ENVIRONMENTAL AND HYDROLOGIC SETTING OF THE OZARK PLATEAUS STUDY UNIT, ARKANSAS, KANSAS, MISSOURI, AND OKLAHOMA

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4022

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

EXHIBIT
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by James C. Adamski, James C. Petersen, David A. Freiwald, *and* Jerri V. Davis

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
foot per day (ft/d)	0.3048	meter per day
cubic foot per day (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pound (lb)	0.4536	kilogram
foot square per day (ft^2/d)	0.09290	meter squared per day

Temperature in degrees Fahrenheit (° F) can be converted to degrees Celsius (° C) as follows:

$$° C = 5/9 \times (° F - 32)$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Environmental and Hydrologic Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma

By James C. Adamski, James C. Petersen, David A. Freiwald, *and* Jerri V. Davis

ABSTRACT

The Ozark Plateaus study is 1 of 20 National Water-Quality Assessment (NAWQA) studies initiated by the U.S. Geological Survey in 1991 to describe the status and trends in the quality of the Nation's water resources. When the NAWQA program is fully implemented, a total of 60 study units in the United States will be investigated on a rotational basis. Study-unit investigations will include 5 years of intensive assessment activity followed by 5 years of low-level monitoring.

The environmental and hydrologic setting of the Ozark Plateaus National Water-Quality Assessment study unit and their factors that affect water quality are described in this report. The primary natural and cultural features that affect water-quality characteristics and the potential for future water-quality problems are described. These environmental features include physiography, climate, population, land use, water use, geology, soils, and surface- and ground-water flow systems.

The Ozark Plateaus study unit has an area of approximately 48,000 square miles and includes parts of Arkansas, Kansas, Missouri, and Oklahoma. The study unit contains most of the Ozark Plateaus Province and parts of the adjacent Osage Plains section of the Central Lowland Province and the Mississippi Alluvial Plain section of the Coastal Plain Province. The Ozark Plateaus Province consists of three sections--the Springfield Plateau, the Salem Plateau, and the Boston Mountains. Topography in the study unit is mostly gently rolling, except in the Boston Mountains and along the escarpment separating the Springfield and Salem Plateaus, where it is rugged. Karst features such as springs, sinkholes, and caves are common in the Springfield Plateau and abundant in the Salem Plateau.

The study unit has a temperate climate with average annual precipitation ranging from about 38 to 48 inches and mean annual air temperature ranging from 56 to 60 degrees Fahrenheit. Population in the study unit was about 2.3 million people in 1990 and increased 28 percent between 1970 and 1990. Land use in the study unit is predominantly pasture and cropland in the northwestern part, and forest and pasture in the southeastern part. Poultry farming is a major industry in the southwestern part of the study unit. Mining, primarily in the four major lead-zinc mining districts, has been an important part of the local economy in the past. Total water use averaged 1,053 million gallons per day in the study unit in 1990. Ground water accounted for about 58 percent of the water withdrawn for all uses; surface water accounted for 42 percent.

Basement igneous rocks of Precambrian age are overlain by as much as 5,000 feet of gently dipping sedimentary rocks throughout much of the study unit. The igneous rocks, which include granite, rhyolite, and diabase, are exposed only in the St. Francois Mountains of southeastern Missouri. The sedimentary rocks include rocks of Cambrian through Ordovician age, which consist of dolomite, sandstone, and limestone with minor amounts of shale; rocks of Mississippian age, which are mostly cherty limestones; rocks of Pennsylvanian age, which consist mostly of shale, sandstone, and limestone; and Post-Paleozoic sediments, which consist of sands, gravels, and clays. The igneous and sedimentary rocks that underlie the study unit are extensively fractured and

faulted. Alfisol and ultisol soil types underlie most of the study unit. These soils are moderately to deeply weathered and have a wide range of hydraulic properties.

All or part of seven major river basins are within the study unit. These basins include the White, Neosho-Illinois, Osage, Gasconade, Meramec, St. Francis, and Black River Basins. Many of the rivers are impounded to form reservoirs. Stream gradients are steepest in the Boston and St. Francois Mountains and least steep in the Osage Plains and Mississippi Alluvial Plain. Streambed material ranges from clay and silt in the Osage Plains to sand, gravel, boulders, and bedrock in most of the Ozark Plateaus Province. Mean annual runoff ranges from 9 to 10 inches in the Osage Plains to 14 to 20 inches in the Boston Mountains. Minimum monthly streamflows generally occur from July through October, and maximum monthly streamflows occur from March through May. Surface- and ground-water interactions are greatest in the Springfield and Salem Plateaus and least in the Boston Mountains and Osage Plains. The ionic composition of surface water generally is calcium or calcium magnesium bicarbonate in the study unit. Dissolved-solids concentrations in water from streams range from about 40 milligrams per liter in the Boston Mountains to as much as 280 milligrams per liter in the Osage Plains, but generally are less than 200 milligrams per liter. Streams in the Boston Mountains generally are the least mineralized and those in the Osage Plains generally are the most mineralized in the study unit.

The study unit contains eight hydrogeologic units that consist of three major aquifers--the Springfield Plateau, Ozark, and St. Francois aquifers--interbedded with four confining units. The unconsolidated sediments of the Mississippi Alluvial Plain are a very productive aquifer, but are of limited areal extent in the study unit. The Springfield Plateau and Ozark aquifers are formed from thick sequences of limestones and dolomites. Rocks in both of these aquifers have secondary porosity as a result of fracturing and dissolutioning and these aquifers are used extensively for sources of water supply. Where the Springfield Plateau aquifer is unconfined, it is extensively used as a source of water for domestic purposes. Well yields in this aquifer generally are less than 20 gallons per minute. The Ozark aquifer is used throughout much of the study unit as a source of water for public and domestic supply. Yields of wells completed in this aquifer commonly range from 50 to 100 gallons per minute but can be as much as 600 gallons per minute. The St. Francois aquifer consists of sandstones and dolomites of Cambrian age. Although well yields in this aquifer can be as much as 500 gallons per minute, the aquifer is rarely used except where it crops out. The ionic composition of ground water in most of the aquifers in the study unit is calcium or calcium magnesium bicarbonate, but locally it can be a calcium sulfate or sodium chloride where the aquifers are confined. Dissolved-solids concentrations generally range from 200 to 300 milligrams per liter, but can be as much as 10,000 milligrams per liter in the deeper aquifers along the western boundary. Ground water in the study unit has a pH of 5.2 to 8.3, locally can contain fecal bacteria, and in some areas has elevated concentrations of radionuclides and nitrates.

Factors that affect water quality in the study unit include geology, land use, and population density. The geochemical processes of mineral dissolution, ion exchange, and oxidation-reduction reactions are the dominant natural factors that affect water quality on a regional scale. Agricultural and mining land-use activities can increase the concentrations of nutrients, bacteria, dissolved solids, sulfate, and trace elements in the surface and ground water of the study unit. Increased population density can result in increased discharges of nutrients, trace elements, bacteria, suspended sediment, and organic compounds.

INTRODUCTION

Nationally consistent information on the status and trends of the Nation's water quality is needed to determine the degree to which past investments in water-quality management are working and to provide a base of knowledge for evaluating future decisions. In 1991, the U.S. Geological Survey (USGS) began to implement the full scale National Water-Quality Assessment (NAWQA) program to provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources. The long-term goals of the NAWQA program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and to provide a better understanding of the natural and human factors that affect the quality of these resources. Investigations will be conducted on a rotational basis in 60 river basins or aquifer systems (referred to as study units) throughout the Nation. Assessment activities began in 20 study units in 1991.

Regional and national synthesis of information from the study units will be the foundation for the comprehensive assessment of the Nation's water quality. Nationally consistent information on water quality, and factors such as climate, geology, hydrology, land use, and agricultural practices, will be integrated to focus on specific water-quality issues that affect large contiguous hydrologic regions. For example, an initial concern in the first 20 study units is the relation of the presence of pesticides in surface and ground water to application rates and cropping practices, and to climatic, geologic, and soil factors. Nutrients and sediment are also central problems to be addressed as part of the synthesis activities, which will contribute to answering fundamental national water-quality questions.

The study unit investigations will consist of 5 years (1991 to 1995) of intensive assessment activity, followed by 5 years (1996 to 2000) of low-level monitoring activity, and then the cycle is repeated. Within each 5-year intensive assessment activity period, there generally will be about 2 years of retrospective data analysis and planning, then 3 years of intensive-data collection (Leahy and others, 1990). The four main components of the intensive assessment activity and timeframe for the first 20 study units in the NAWQA Program are presented in table 1.

The retrospective analysis includes reviewing and analyzing existing hydrologic data to provide a historical perspective on water quality to aid in the design of the study unit intensive data-collection phase. The occurrence and distribution assessment will characterize the broad-scale geographic and seasonal distributions of water-quality conditions through sampling of surface- and ground-water resources and performing ecological surveys. Long-term monitoring will assess the status and trends of selected aspects of water-quality conditions. Case studies of sources, transport, and effects will address specific questions about water-quality changes related to specific contaminants in selected areas.

In 1991, the Ozark Plateaus study unit was among the first 20 NAWQA study units selected for study under the full-scale implementation plan. The complex, mostly karst aquifer system of the Ozark Plateaus study unit coupled with the influx of people and probability of future growth makes this area extremely susceptible to water-resources contamination. Four major water-quality issues were identified jointly by USGS personnel and representatives of various Federal, State, and local agencies in Arkansas, Kansas, Missouri, and Oklahoma that served on a coordination committee, the Ozark Plateaus NAWQA Liaison Committee. The recurring local or regional water-quality issues identified in the Ozark Plateaus study unit include problems associated with nutrients and bacteria, trace elements and dissolved solids, radionuclides in ground water, and saline ground-water encroachment.

Elevated levels of nitrate, ammonia, and bacteria in surface and ground waters have resulted from the expanding poultry, cattle, and swine industry in northern Arkansas and southern Missouri. Arkansas is the leading poultry producer, and Missouri is the second leading producer of beef cattle in the United States.

Lead, zinc, and other trace elements are present in surface and ground waters in part of the Ozark Plateaus study unit, as a result of mining activities. Missouri has been a leading producer of lead and zinc ore in the United States since the 1800's. Numerous abandoned lead and zinc mines that are now flooded are located in southwestern Missouri, southeastern Kansas, and northeastern Oklahoma. Water in these mines typically contains higher than normal concentrations of trace elements and dissolved solids. Lead mining of the Viburnum Trend or New Lead Belt of southeastern Missouri is expected to continue at present levels to the year 2000.

Naturally occurring radioactivity (radium-226 and -228) in ground water in excess of the maximum contaminant levels (MCL's) established for drinking water by the U.S. Environmental Protection Agency has been detected in the Ozark aquifer. Radionuclides are present primarily along the saline-freshwater transition zone on the western boundary of the Ozark Plateaus in Kansas, Missouri, and Oklahoma; St. Francois

Table 1. Timeframe of National Water-Quality Assessment program intensive assessment activity for the first 20 study units

Activity	Fiscal year (October through September)				
	1991	1992	1993	1994	1995
Retrospective Analysis and Planning					
Retrospective Data Analysis	|------	------	------|		
Water-Quality Reconnaissance		|------|			
Occurrence and Distribution Assessment					
SURFACE WATER					
Bed Sediment and Tissues					
Occurrence Survey		|------|			
Spatial Distribution Survey			|------	---|	
Water Column					
Basic Fixed Stations			|------	------	------|
Intensive Fixed Sites				|------|	
Synoptic Studies			|------	------	------|
ECOLOGY					
Ecological Survey Prototype		|--	--|		
Ecological Survey			|------	------	------|
GROUND WATER					
Study-Unit Survey		|------	------|		
Land-Use Studies			|---	------	---|
Flowpath Studies				|------	---|
Long-term Monitoring				|------	------>
Case Studies of Sources, Transport, and Effects			|------	------	------|
	1991	1992	1993	1994	1995

County in Missouri; and Newton and Searcy Counties in Arkansas.

The saline-freshwater transition zone lies along the entire western boundary of the study unit in the Ozark Plateaus aquifer system. The use of ground water near this transition zone has caused water levels to decline from 100 to 300 ft in places and has induced movement of highly saline ground water from the west into some well fields, resulting in ground water from these well fields that may be unsuitable for many uses.

Purpose and Scope

The purpose of this report is to describe the environmental and hydrologic setting of the Ozark Plateaus study unit and the factors that affect water quality. This report is the first in a series of NAWQA reports on the Ozark Plateaus study unit. It is intended to be used as a general reference for the environmental setting of the study unit and as background information for subsequent in-depth topical reports on water quality and aquatic biology.

The report describes the climate, physiography, geology, soils, population, land use, water use, and surface- and ground-water systems in the study area. Factors that affect surface- and ground-water quality are described for the primary natural and cultural environmental features of climate, physiography, geology, soils, population, land use, and water use. These environmental features largely determine water-quality characteristics and the potential for future water-quality issues in the area. Only a brief description of selected water-quality characteristics is included in this report.

Location

The Ozark Plateaus study unit area is approximately 48,000 mi^2 and includes parts of four States: northern Arkansas, southeastern Kansas, southern Missouri, and northeastern Oklahoma (fig. 1). The study unit includes most of the about 40,000 mi^2 Ozark Plateaus Province as well as parts of the surrounding Central Lowland Province known as the Osage Plains section, and a small part of the Mississippi Alluvial Plain section of the Coastal Plain Province. The study-unit boundary approximates the natural flow boundaries of the Ozark Plateaus aquifer system (Imes and Emmett, 1994) but has been truncated on the north, east, and south to include only those major hydrologic units that exist in the core of the Ozark Plateaus Province. The western study-unit boundary extends beyond the Ozark Plateaus physiographic province to include the complex ground-water transition zone where fresh ground water from the Ozark Plateaus mixes with saline ground water from the Western Interior Plains aquifer system (Imes and Emmett, 1994). The northern boundary of the Ozark Plateaus study unit coincides with the northern boundaries of the Osage, Gasconade, and Meramec Rivers hydrologic unit boundary. The eastern boundary of the study unit coincides with the eastern boundaries of the Meramec and upper St. Francis River hydrologic unit boundary. The southeastern boundary of the study unit coincides with the eastern boundary of the Black River hydrologic unit boundary. The southern boundary of the study unit coincides with the drainage divide in the Boston Mountains.

Previous Investigations

The NAWQA program concepts and plans are described in reports by Hirsch and others (1988) and Leahy and others (1990). The water-quality issues, objectives, and approach for this study have been described by Freiwald (1991).

Numerous hydrologic or environmental investigations of all or parts of the Ozark Plateaus region have been made in the past. Climatic information, mostly relating to precipitation in the study unit, has been described by Dugan and Peckenpaugh (1985) and Freiwald (1985). Information on temperature and potential evapotranspiration has been published by Dugan and Peckenpaugh (1985) and Hanson (1991). Physiography of the area has been described by Fenneman (1938). Population data from the 1990 census have been published for individual states by the U.S. Department of Commerce, Bureau of Census (1990). Land use in the study unit has been described by Rafferty (1980) and Dugan and Peckenpaugh (1985). Geologic investigations in the study unit include those by Snider (1915) in northeastern Oklahoma; Howe and Koenig (1961) in Missouri; and Croneis (1930), Caplan (1957; 1960), and Frezon and Glick (1959) in northern Arkansas.

The Central Midwest Regional Aquifer-System Analysis (CM RASA) study completed in 1985 investigated the geohydrology of the Ozark Plateaus Province and adjacent areas, and provided much of the geologic and hydrogeologic foundation for this report (Jorgensen and Signor, 1981). In that study, Imes and Emmett (1994) identified the major geohydrologic units in the Ozark Plateaus, described the regional factors that control ground-water flow, and constructed a digital ground-water flow model of the Ozark Plateaus aquifer system. A series of map reports on the major aquifers and confining units in the Ozark Plateaus were produced by Imes (1990a-g). These reports describe the outcrop area, structure, thickness, potentiometric surface, and dissolved solids concentration of water in the aquifer, and percentage shale in the confining units. Also in this map series are reports by Imes and Davis (1990a, b; 1991), which describe water type, and concentration of dissolved solids, chloride, and sulfate in water from the St. Francois, Ozark, and Springfield Plateau aquifers.

A general summary of the hydrology of aquifers in the Springfield and Salem Plateaus of southern Missouri and northern Arkansas is presented in Harvey (1980). Christenson and others (1990) described the geology, hydrology, and water quality of the Roubidoux aquifer in northeastern Oklahoma. Lamonds (1972) described the occurrence, availability, and chemical quality of ground and surface water for the Ozark Plateaus of northern Arkansas. The hydrology and geochemistry of the lead-zinc mined areas of Cherokee County, Kansas, and adjacent areas are described by Spruill (1987).

Runoff and streamflow characteristics for Ozark Plateaus streams are presented in a report by Hedman and others (1987). Gann and others (1974; 1976) presented a general summary of information about the occurrence, availability, use, and quality of water in that part of Missouri south of the Missouri River. Information on major streams and reservoirs in Missouri have

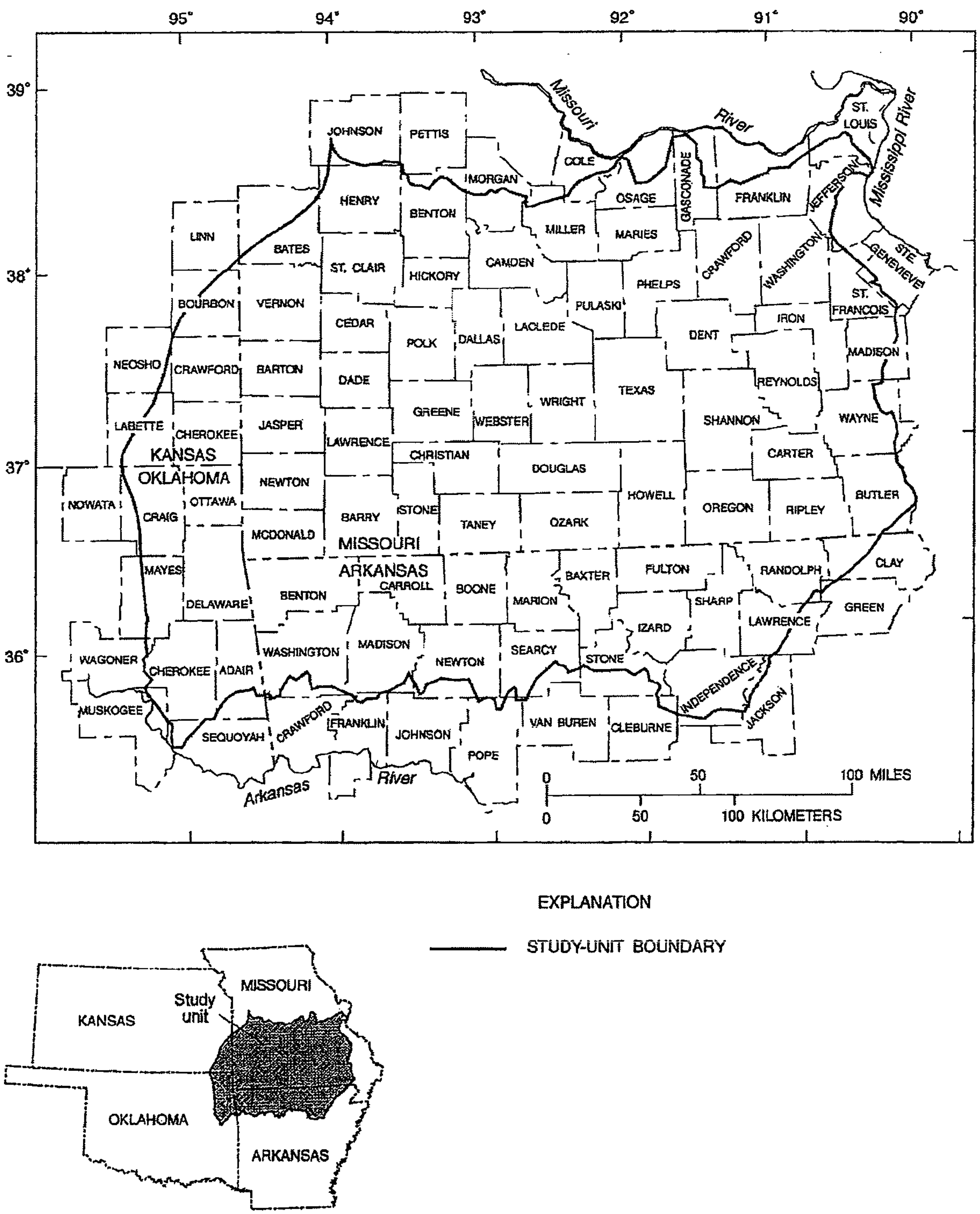


Figure 1. Ozark Plateaus National Water-Quality Assessment study unit location.

been described by Homyk and Jeffery (1967), U.S. Army Corps of Engineers (1967), Duchrow (1984), and Pflieger (1989). Information on surface-water quality has been presented in reports by Lamonds (1972), Gann and others (1974; 1976), Stoner (1981), Bennett and others (1987), Petersen (1988), Davis and Howland (1993), Petersen and others (1993), Kurklin and Jennings (1993), and Kenny and Snethen (1993).

ENVIRONMENTAL SETTING

Climate

The Ozark Plateaus study unit has a temperate climate because of its mid-latitude, interior-continent location. Major weather systems normally move from west to east during the fall, winter, and spring seasons. In early spring, the study unit receives moisture-laden air from the Gulf of Mexico, which often results in thunderstorms, tornadoes, and intense rainfall. Thunderstorms are responsible for most of the severe weather in the study unit. The severe weather season extends from March through June, although thunderstorms can occur throughout the year and occasionally cause flash floods.

Average annual precipitation generally increases toward the southeast from about 38 in/yr (inches per year) in the northern part of the study unit to about 48 in/yr near the southern boundary (fig. 2). Average seasonal precipitation during the cool season (October through March) ranges from around 12 in. in the northwestern part of the study unit to 24 in. in the southeastern part. Average precipitation during the warm season (April through September) ranges from 22 in. in the northeastern part of the study unit to 26 in. in the southwestern part (Dugan and Peckenpaugh, 1985). Average monthly precipitation indicates a seasonal pattern (fig. 3). Precipitation generally is greatest in the late spring (April to June) and least in late winter (December to February).

Mean annual air temperature ranges from 56 °F in the northeastern part of the study unit to 60 °F in the southwestern part (fig. 4). Mean monthly temperatures generally are lowest in January and highest in July. The mean temperature during January ranges from 30 °F in the northern part of the study unit to 38 °F in the southern part. The mean temperature during July ranges from 78 °F along the eastern boundary of the study unit to about 82 °F along the southwestern boundary. The seasonal variation in mean temperatures is closely related to seasonal solar radiation with greater regional contrasts in winter than in summer. Also, the polar front and jet stream normally pass through the study unit in winter causing increased temperature contrasts within the study unit (Dugan and Peckenpaugh, 1985).

The estimated mean annual evapotranspiration rate in the study unit is 30 to 35 in/yr. Seasonal trends in evapotranspiration follow the seasonal trends in air temperature and solar radiation; the maximum rate occurs during the summer, and the minimum rate occurs during the winter. Evapotranspiration fluctuates daily as well as seasonally. In clear weather, the rate increases through the morning and reaches a maximum in early to midafternoon (Hanson, 1991).

Precipitation in the study unit generally is acidic with low dissolved-solids concentrations. In 1990, the pH of precipitation ranged from about 4.6 to 5.0, and the sum of the major cations--calcium, magnesium, sodium, and potassium--was less than 0.5 mg/L (milligram per liter; National Atmospheric Deposition Program, 1991).

Physiography

The Ozark Plateaus study unit includes most of the Ozark Plateaus Province and small parts of the Osage Plains and Mississippi Alluvial Plain of the Central Lowland and Coastal Plain Provinces, respectively (fig. 5). These three major physiographic provinces include a diverse range of topography and geomorphology, which greatly affects the hydrology of the area. Altitudes in these provinces range from greater than 200 ft in the Mississippi Alluvial Plain to more than 2,300 ft in the Boston Mountains.

Ozark Plateaus Province

The Ozark Plateaus Province has an area of about 40,000 mi^2 and includes parts of four states. The physiography of this province is largely controlled by the geology of the area; a structural dome underlies most of the province. Sedimentary rocks of Paleozoic age flank a core of igneous rocks at the center of the structural dome in southeastern Missouri. The igneous rocks form the St. Francois Mountains. The sedimentary rocks, which dip gently away from the center of the dome, form three distinct physiographic sections--the

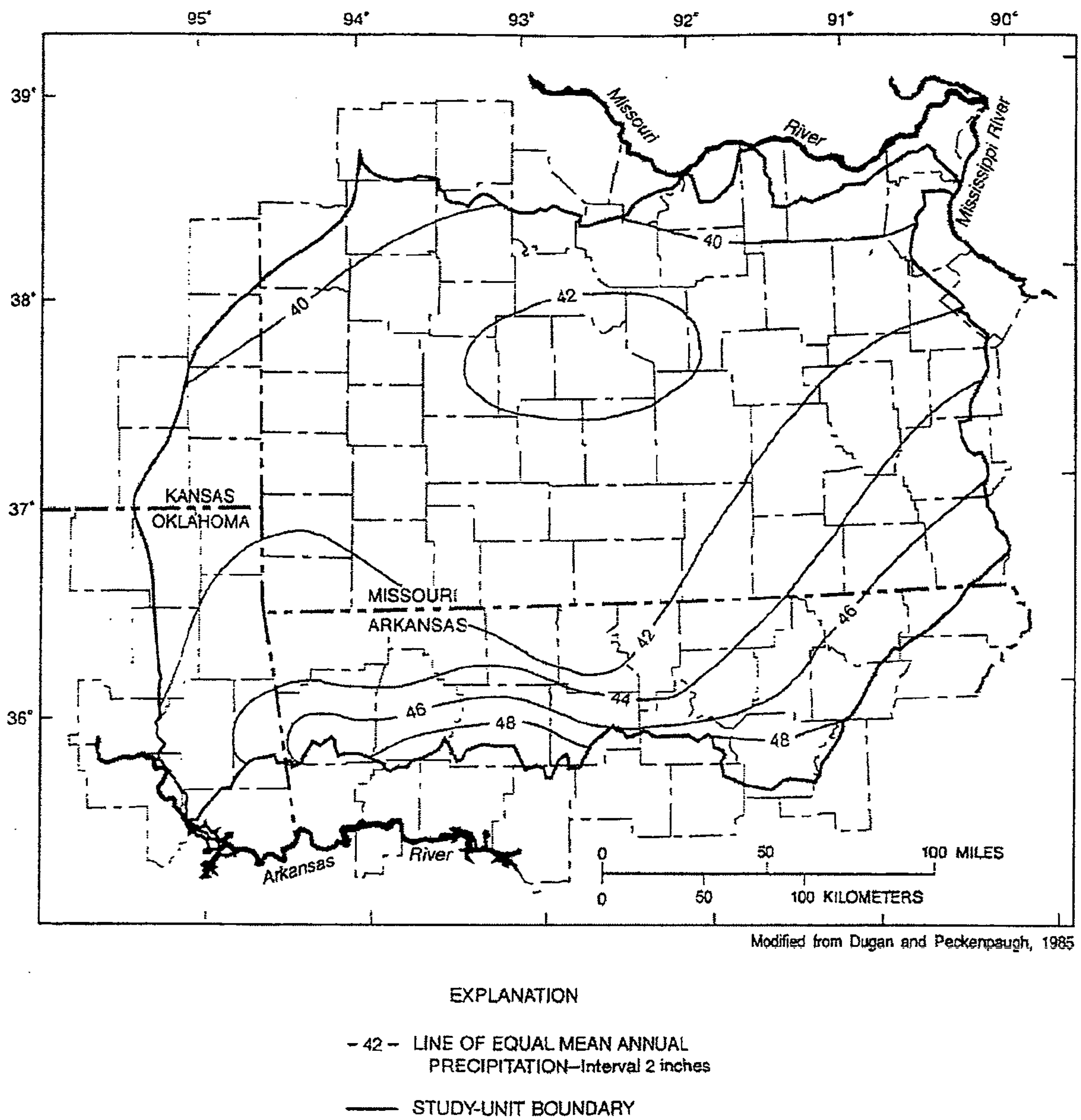
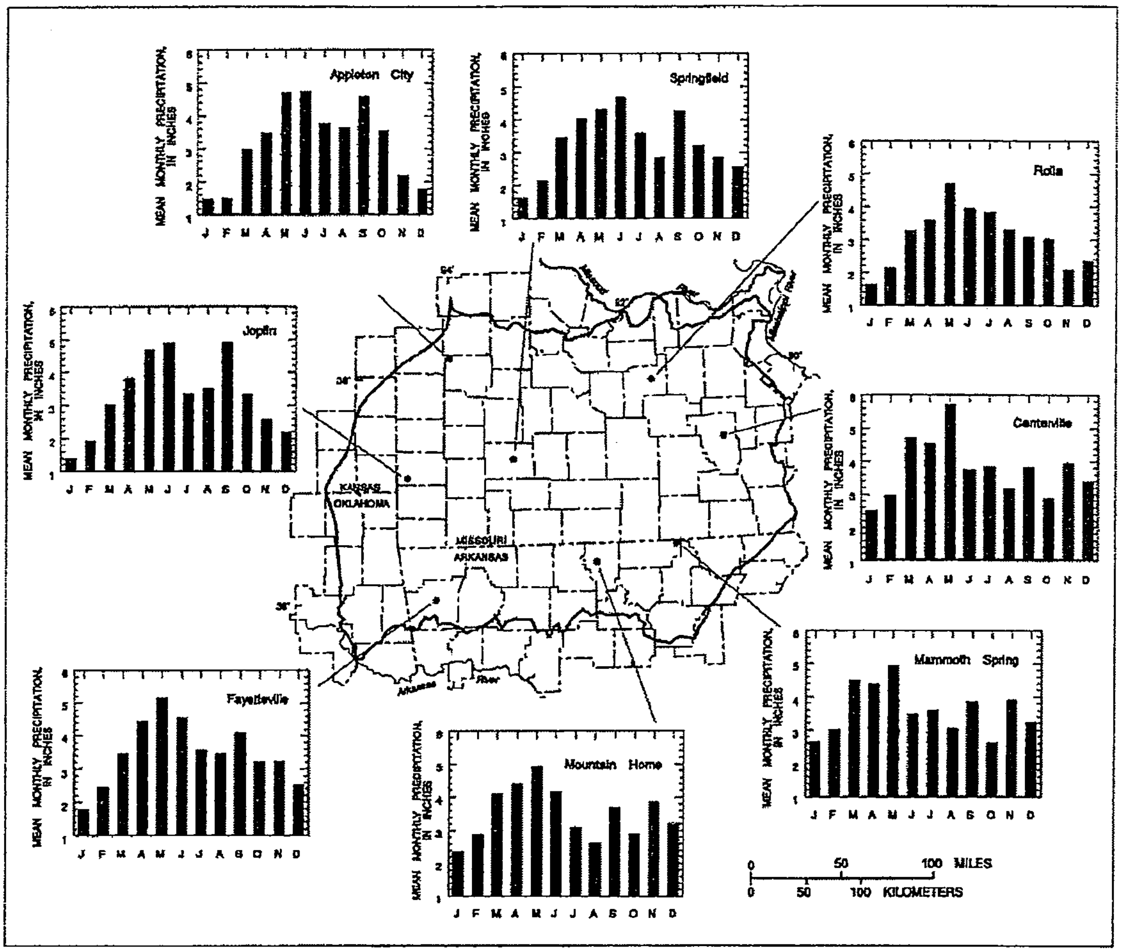


Figure 2. Mean annual precipitation in the Ozark Plateaus study unit, 1951-80.



Data from U.S. Department of Commerce, National Ocear and Atmospheric Administration, 1990

EXPLANATION

—— STUDY-UNIT BOUNDARY

• LOCATION OF CITY

Figure 3. Mean monthly precipitation for selected cities in the Ozark Plateaus study unit, 1951-80.

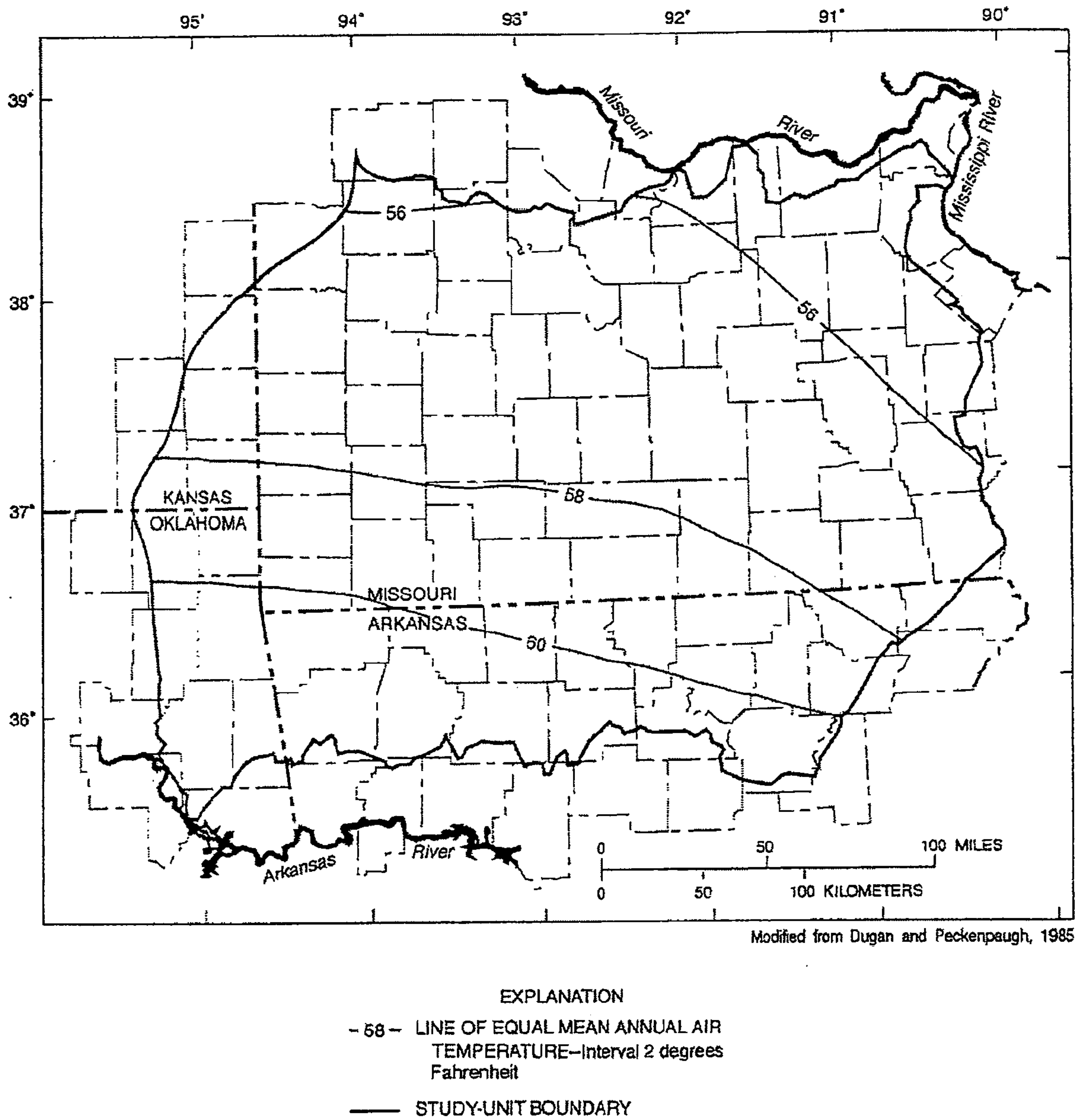


Figure 4. Mean annual air temperature in the Ozark Plateaus study unit, 1951-80.

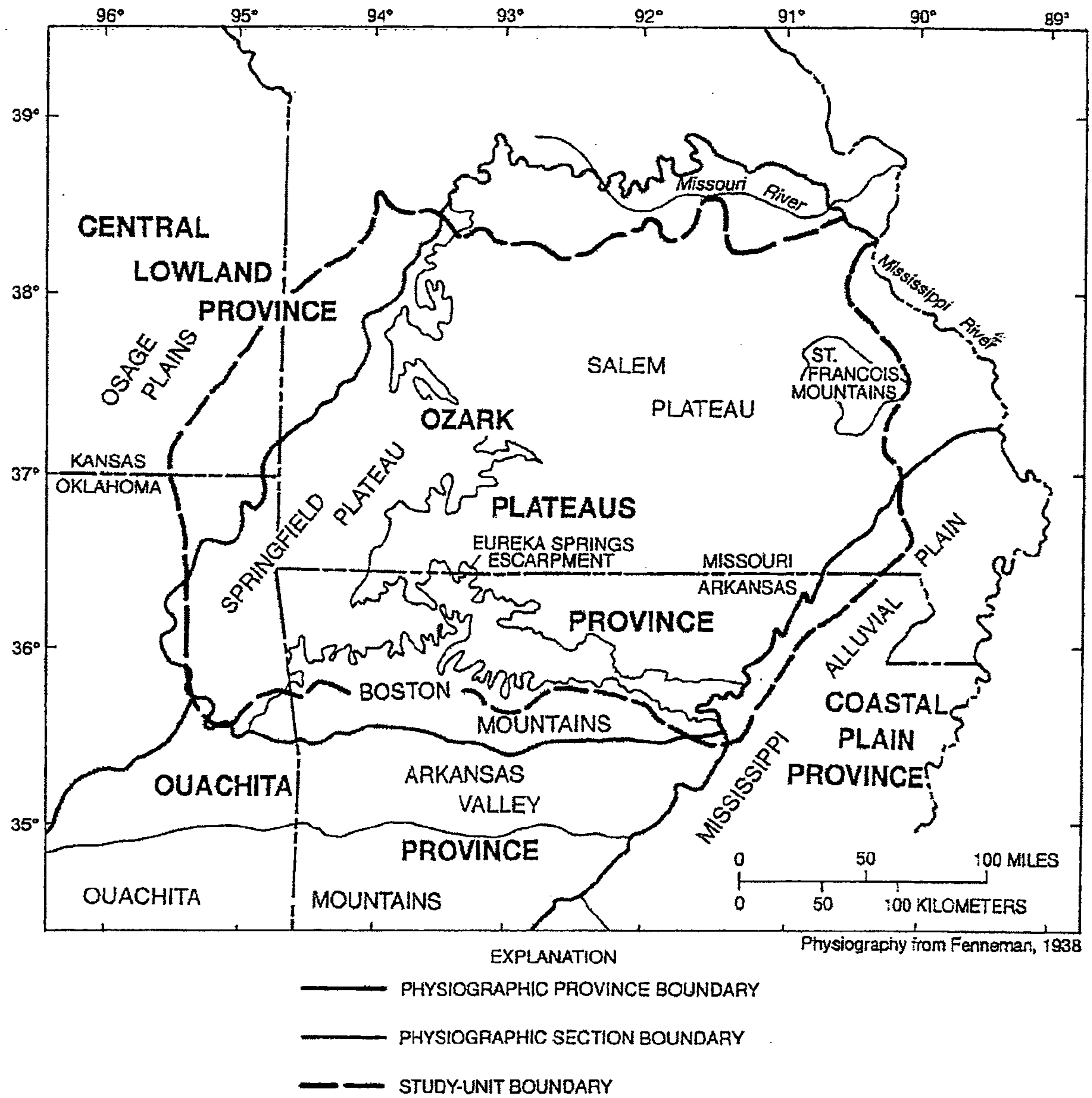


Figure 5. Physiographic subdivisions of the Ozark Plateaus study unit and adjacent areas.

Springfield Plateau, the Salem Plateau, and the Boston Mountains (Fenneman, 1938). In this report, each of these sections generally will be referred to without the physiographic section nomenclature. For example, the Salem Plateau section will be referred to as the "Salem Plateau."

The southeastern boundary of the Ozark Plateaus Province is marked by the contact between rocks of Paleozoic age of the Ozark Plateaus and younger, unconsolidated sediments of the Mississippi Alluvial Plain. The southern boundary is marked by faults on the southern flank of the Boston Mountains, although the southern boundary of the study unit is the east-west trending drainage divide formed by the Boston Mountains. The western boundary of the province is marked by the contact between rocks of Mississippian and Pennsylvanian age. The northern and eastern boundaries of the province generally follow the Missouri and Mississippi Rivers, respectively. However, an area containing rocks of Devonian age and older exposed in Illinois and structurally a part of the Ozark Plateaus Province (Fenneman, 1938) is not included as part of the study-unit area.

The highest land surface altitude in the study unit outside the Boston Mountains is 1,772 ft above sea level at Taum Sauk Mountain in the St. Francois Mountains. A ridge of locally high relief extends west-southwest from the St. Francois Mountains to the extreme southwestern corner of Missouri. Altitudes along this ridge range from 1,200 ft to more than 1,600 ft above sea level. Altitudes generally decrease to the northwest and south of this ridge (Fenneman, 1938).

Topography in the province ranges from nearly flat-lying to rugged. The boundaries between each plateau are characterized by escarpments where deeply incised valleys separate narrow divides or "mountains." The result is rugged topography with relatively high relief. Away from the escarpments, topography is nearly flat-lying to gently rolling hills with low relief. The exception is the Boston Mountains, which has rugged topography nearly everywhere (Fenneman, 1938).

Stream drainage patterns are radial, away from regional and local topographic highs. Drainage patterns can follow geologic features such as faults and joints in the rocks. Entrenched meanders, resulting from the downcutting of streams as the area was uplifted, are common in the larger stream valleys.

The Ozark Plateaus Province contains numerous distinctive geomorphic features. The development of these features generally is related to the geology and hydrology of the area. For example, local topographic highs can form two distinct geomorphic features--mounds and bald mountains. Mounds are erosional remnants of outliers of rocks of Mississippian or Pennsylvanian age overlying older sedimentary rocks. Bald mountains, commonly called "balds," are predominantly tree-less hills present in south-central Missouri. Lines of trees on bald mountains can indicate water-bearing fractures in the rock (Beveridge and Vineyard, 1990).

Karst features are common in the Ozark Plateaus. Dissolution of carbonate rocks along fractures and faults has produced cave systems, sinkholes, and natural tunnels in the area (Beveridge and Vineyard, 1990). Missouri alone contains at least 5,000 caves, most of which are located in the Ozark Plateaus Province (Missouri Department of Natural Resources, 1980).

Filled paleo-sinkholes sometimes contain, and were mined for, iron, lead, and zinc ores. One of the largest of these filled sinkholes is the Oronogo Circle in Jasper County, Missouri. This sinkhole is 1,000 ft in diameter, and has been mined to depths as much as 190 ft deep (Beveridge and Vineyard, 1990).

Salem Plateau

The Salem Plateau includes a large part of the study unit (approximately 27,200 mi^2) in Missouri and northern Arkansas (fig. 5). It is underlain by rocks of Cambrian and Ordovician age. The Salem Plateau contains a central upland area, which is present west of the St. Francois Mountains in Dallas, Laclede, Polk, Webster, and Wright Counties, Missouri (fig. 1). The upland generally is characterized by gently rolling hills. Local relief in the upland area is 50 to 100 ft (Fenneman, 1938).

Away from the upland area, the plateau is dissected by numerous streams, which results in increased relief. South and east of the upland, topography is rugged, and relief can be as much as 500 ft. North of the upland, topography is rugged, but relief rarely exceeds 350 ft (Fenneman, 1938).

Sinkholes and springs are abundant in the Salem Plateau. On average, the upland area has 1 to 10 sinkholes per 100 mi^2 (fig. 6). A north-south trending band in south-central Missouri contains more than 10 sinkholes per 100 mi^2 (Harvey, 1980). Large springs with discharges exceeding 100 ft^3/s are common in some areas of the Salem Plateau (Imes and Smith, 1990).

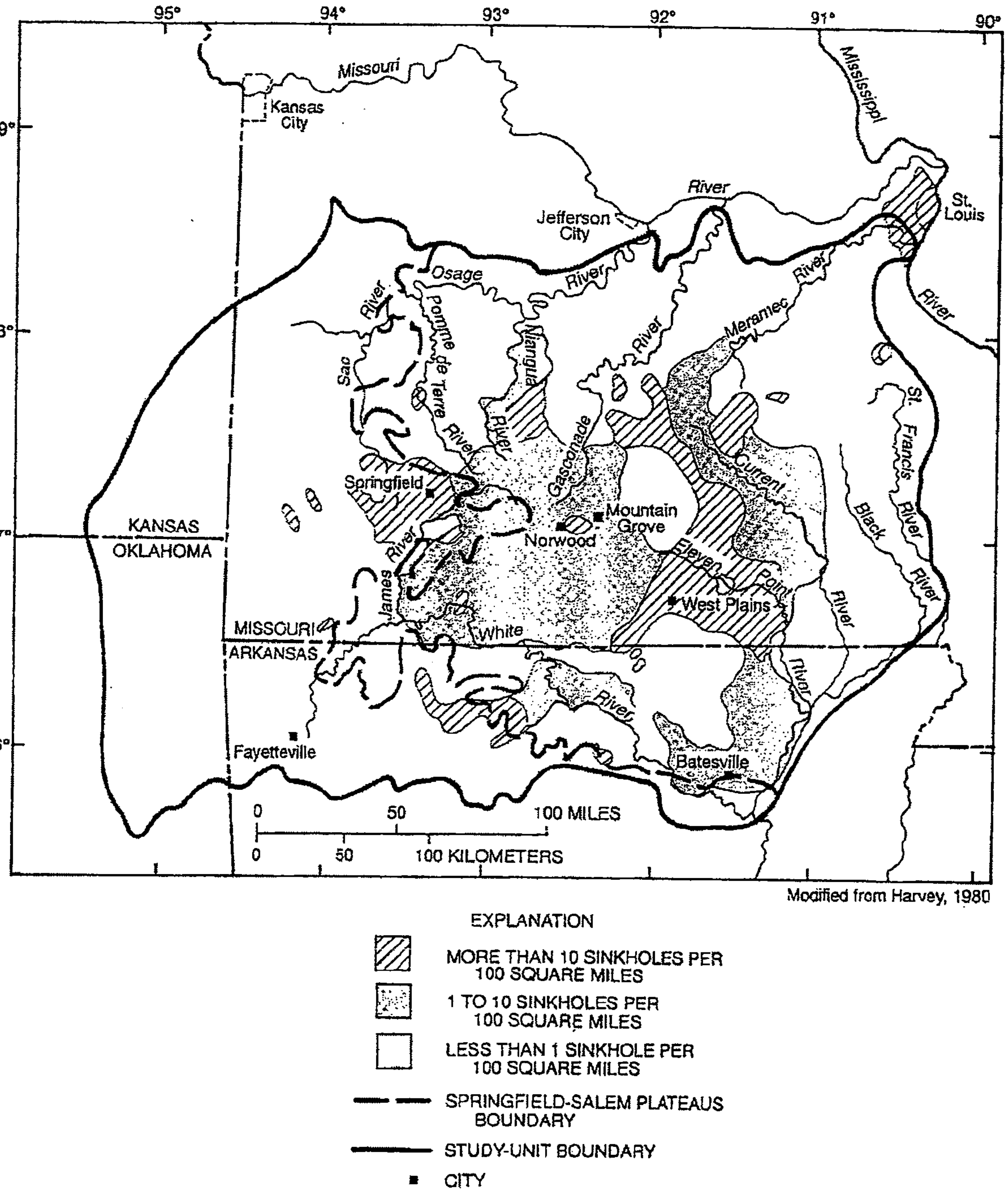


Figure 6. Distribution of sinkholes in southern Missouri and northern Arkansas.

The St. Francois Mountains are within the Salem Plateau and are formed from exposures of igneous rocks of Precambrian age associated with the structural dome in southeastern Missouri. The St. Francois Mountains are a series of resistant hills or knobs separated by valleys that are underlain by sedimentary rocks of Cambrian age. The St. Francois Mountains occupy an area of approximately 1,350 mi^2, but the area in which predominantly igneous rocks are exposed is less than 100 mi^2 (Fenneman, 1938). Land surface altitudes range from 1,000 to more than 1,700 ft above sea level. Topography is rugged and relief ranges from 500 to 800 ft (Fenneman, 1938). The St. Francois Mountains are not a separate physiographic section as defined by Fenneman (1938), but will often be discussed in this report separately because of its unique geological features, which affect the hydrology of the area.

Springfield Plateau

The Springfield Plateau occupies an area of approximately 10,300 mi^2 in the study unit including parts of west-central and southwestern Missouri, southeastern Kansas, northeastern Oklahoma, and northern Arkansas (fig. 5). The Plateau is underlain by limestones and cherty limestones of Mississippian age (Fenneman, 1938).

Land-surface altitudes in the Springfield Plateau range from 1,000 to 1,700 ft, but locally topographic relief, which decreases from east to west, rarely exceeds 200 to 300 ft. Topography is mostly gently rolling hills, except at the Eureka Springs Escarpment (fig. 5), which separates the Springfield and Salem Plateaus, where deeply incised stream valleys separate narrow divides (Fenneman, 1938).

Sinkholes and springs are common in the Springfield Plateau, but generally are smaller and less abundant there than in the Salem Plateau. The number of sinkholes in the Springfield Plateau generally averages less than 1 per 100 mi^2 except near the city of Springfield, Missouri, where there are more than 10 sinkholes per 100 mi^2 (fig. 6).

Boston Mountains

The Boston Mountains occupy an area of approximately 2,400 mi^2 in a 200-mi wide band extending through northern Arkansas and northeastern Oklahoma (fig. 5). They are underlain by sandstones, shales, and limestones of late Mississippian to Pennsylvanian age. Land-surface altitudes in the Boston Mountains range from 1,200 to more than 2,300 ft above sea level. Topographic relief is as much as 1,000 ft in some places. The topography is rugged, with narrow divides separating steep-sided valleys (Fenneman, 1938).

Central Lowland and Coastal Plain Provinces

The Central Lowland Province occupies a large area in the central United States extending from Texas to North Dakota and from Missouri to Colorado (Fenneman, 1938). The Osage Plains section of this province includes an area in the western and northwestern part of the study unit.

The Coastal Plain Province is another extensive province, extending along the Atlantic and Gulf Coasts from New England to Texas. It is a continuation of the Continental Shelf and has a very gentle slope. The Mississippi Alluvial Plain section of this province, which is an area of delta and bottomlands of the Mississippi River and tributaries (Fenneman, 1938), includes a small area in the southeastern part of the study unit.

Osage Plains

The Osage Plains occupies an area of approximately 6,700 mi^2 in the western and northwestern part of the study unit (fig. 5). The Osage Plains is underlain by soft shales with interbedded sandstones and limestones of late Mississippian to Pennsylvanian age. Land-surface altitudes in the part of the study unit in the Osage Plains range from 800 to 1,000 ft. In general, topography in this part of the study unit consists of gently rolling hills, but in some areas resistant beds of sandstones and limestones form rare east-facing escarpments (Fenneman, 1938).

Mississippi Alluvial Plain

The Mississippi Alluvial Plain includes a small area of approximately 1,100 mi^2 in the southeastern part of the study unit (fig. 5). The Mississippi Alluvial Plain is a flat to gently-rolling plain underlain by unconsolidated sediments of Cretaceous through Quaternary age. Land-surface altitudes in the part of the study unit in the Mississippi Alluvial Plain average just over 200 ft above sea level and topographic relief seldom exceeds 30 ft.

The formation of the plains is partially structural and partially erosional. The boundary between the unconsolidated sediments of the Mississippi Alluvial Plain and sedimentary rocks of Paleozoic age is formed by normal faults. Faulting has resulted in subsidence of the older sedimentary rocks, allowing a thick sequence of unconsolidated sediments to be deposited on top. The Mississippi River and its tributaries have eroded the unconsolidated sediments in places, forming occasional bluffs and ridges in the section (Fenneman, 1938).

Geologic Setting

The geology of the Ozark Plateaus study unit is diverse in lithology, mineralogy, and structure. Lithologies include igneous and sedimentary rocks. Secondary mineralization has occurred in many of the rock units, and uplifting has resulted in fracturing and faulting of the rock units.

Stratigraphy

The stratigraphy of the Ozark Plateaus study unit is complex. The basement crystalline rocks in the study unit are overlain by a sequence of sedimentary rocks of Paleozoic age (fig. 7). The sedimentary-rock sequence consists predominantly of dolomites and limestones of Cambrian through Mississippian age in some areas and sandstones and shales of Pennsylvanian age in other areas. In addition, lateral changes in lithology, the absence of some geologic units in parts of the study unit, and nomenclature, which has evolved independently in the four states, result in different stratigraphic sequences over the study unit (Imes and Emmett, 1994). These units are briefly described in the following section.

Precambrian Units

Igneous and metamorphic rocks of Precambrian age underlie the Ozark Plateaus and crop out in several places in the eastern part of the study unit (fig. 8). Elsewhere, these rocks are buried under as much as 5,000 ft of sedimentary rock. Structural relief of the rocks can be as much as 1,000 ft in a few miles (Imes and Emmett, 1994). These igneous rocks are mainly felsic (silica rich) rocks such as granite and rhyolite with mafic (silica poor) intrusions consisting of diabase and gabbro (Kisvarsanyi, 1981). Felsic rocks contain minerals such as quartz and potassium feldspar, which are resistant to weathering. In contrast, the mafic rocks contain minerals such as pyroxene and calcium plagioclase, which weather easily.

The igneous rocks of Precambrian age also contain commercially important quantities of several trace elements, including iron, lead, manganese, and silver (Kisvarsanyi, 1981). In addition, uranium and thorium are present in some of these rocks (primarily the granites) in concentrations as large as 34 and 54 mg/kg (milligrams per kilogram), respectively (Kisvarsanyi, 1987).

Cambrian and Ordovician Units

Rocks of Cambrian and Ordovician age in the study unit crop out mainly in the Salem Plateau (fig. 8). The geologic units of Cambrian and Ordovician age range in thickness from less than 50 ft to more than 4,000 ft; and average about 2,000 ft thick (Imes, 1990b, c, d). In general, the units consist predominantly of dolomites, cherty dolomites, sandstones, and limestones (Caplan, 1960), although shales are present in some areas mainly as discontinuous beds and thin partings.

The basal unit of the Cambrian and Ordovician rocks, the Lamotte Sandstone of Late Cambrian age, rests unconformably on igneous rocks of Precambrian age. It is a well-sorted quartz sandstone, which is arkosic and conglomeratic at its base. Its thickness ranges from less than 50 ft to nearly 500 ft. The Lamotte Sandstone grades upward into the Bonneterre Dolomite or equivalent, which is also of Cambrian age (Caplan, 1960).

The Bonneterre Dolomite is a fine- to medium-grained dolomite that crops out in the vicinity of the St. Francois Mountains. It contains glauconite and pyrite, and it can contain locally minor amounts of chert and shale. It is 200 to 300 ft in thickness near the St. Francois Mountains, but the thickness decreases southward to about 70 ft in northern Arkansas (Caplan, 1960). In southeastern Missouri, the Bonneterre Dolomite is extensively mineralized, containing abundant lead- and zinc-sulfide deposits. Other trace elements, such as cobalt, copper, nickel, and silver, are present in lower concentrations in the Bonneterre Dolomite (Wharton and others, 1975).

The Davis Formation and Derby-Doe Run Dolomite are shaly to silty, glauconitic dolomites that crop out in a roughly circular band around the St. Francois Mountains (Caplan, 1960). Thickness of the Davis Formation near its type locality is about 160 ft; thickness of the Derby-Doe Run Dolomite is about 115 ft (Howe

ERATHEM	SYSTEM	SOUTHERN MISSOURI	SOUTHEASTERN KANSAS	NORTHEASTERN OKLAHOMA	NORTHERN ARKANSAS	HYDROGEOLOGIC UNIT	HYDROGEOLOGIC SYSTEM
		Post-Paleozoic sediments					
PALEOZOIC	PENNSYLVANIAN	Kansas City Group Pleasanton Formation Marmaton Group Cherokee Shale	Kansas City Group Pleasanton Group Marmaton Group Cherokee Group	Marmaton Group Cabaniss Group Krebs Group Atoka Formation Bloyd Shale Hale Formation	Atoka Formation Bloyd Shale Hale Formation		Western Interior Plains confining system
	MISSISSIPPIAN	Fayetteville Shale Batesville Sandstone Hindsville Limestone Carterville Formation		Pitkin Limestone Fayetteville Shale Batesville Sandstone Hindsville Limestone	Pitkin Limestone Fayetteville Shale Batesville Sandstone		
		St. Louis Limestone Salem Limestone Warsaw Limestone Keokuk Limestone Burlington Limestone Elsey Formation Reeds Spring Limestone Pierson Formation	St. Louis Limestone Salem Limestone Warsaw Limestone Keokuk Limestone Burlington Limestone Fern Glen Limestone	Moorefield Formation Keokuk Limestone Boone Formation St. Joe Limestone	Moorefield Formation		
					Boone Formation St. Joe Limestone	Springfield Plateau aquifer	Ozark Plateaus aquifer system

Figure 7. Geologic and hydrogeologic units in the Ozark Plateaus study unit and adjacent areas (modified from Imes, 1990a).

PALEOZOIC	MISSISSIPPIAN	Northview Shale Sedalia Limestone Compton Limestone	Chouteau Limestone	Northview Equivalent Compton Equivalent		Ozark confining unit	Ozark Plateaus aquifer system
	DEVONIAN	Chattanooga Shale	Chattanooga Shale	Woodford Chert Chattanooga Shale	Chattanooga Shale		
		Callaway Formation Fortune Formation		Sallisaw Formation Frisco Limestone	Clifty Limestone Penters Chert	Ozark aquifer	
	SILURIAN			St. Clair Limestone	Lafferty Limestone St. Clair Limestone Brassfield Limestone		
	ORDOVICIAN	Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone		Sylvan Shale Fernvale Limestone Viola Limestone Fite Limestone Tyner Formation Burgen Sandstone	Cason Shale Fernvale Limestone Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone		

Figure 7. Geologic and hydrogeologic units in the Ozark Plateaus study unit and adjacent areas (modified from Imes, 1990a)—Continued.

PALEOZOIC	ORDOVICIAN	Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone	Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Van Buren Formation	Smithville Equivalent Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Van Buren Formation	Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone Van Buren Formation	Ozark aquifer	Ozark Plateaus aquifer system
	CAMBRIAN	Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite		
		Derby-Doe Run Dolomite Davis Formation	Derby-Doe Run Dolomite Davis Formation	Derby-Doe Run Dolomite Davis Formation	Derby-Doe Run Dolomite Davis Formation	St. Francois confining unit	
		Bonneterre Dolomite Reagan Sandstone Lamotte Sandstone	Bonneterre Equivalent Reagan Sandstone Lamotte Sandstone	Bonneterre Equivalent Reagan Sandstone Lamotte Sandstone	Bonneterre Dolomite Reagan Sandstone Lamotte Sandstone	St. Francois aquifer	
PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS						Basement confining unit	

Figure 7. Geologic and hydrogeologic units in the Ozark Plateaus study unit and adjacent areas (modified from Imes, 1990a)—Continued.

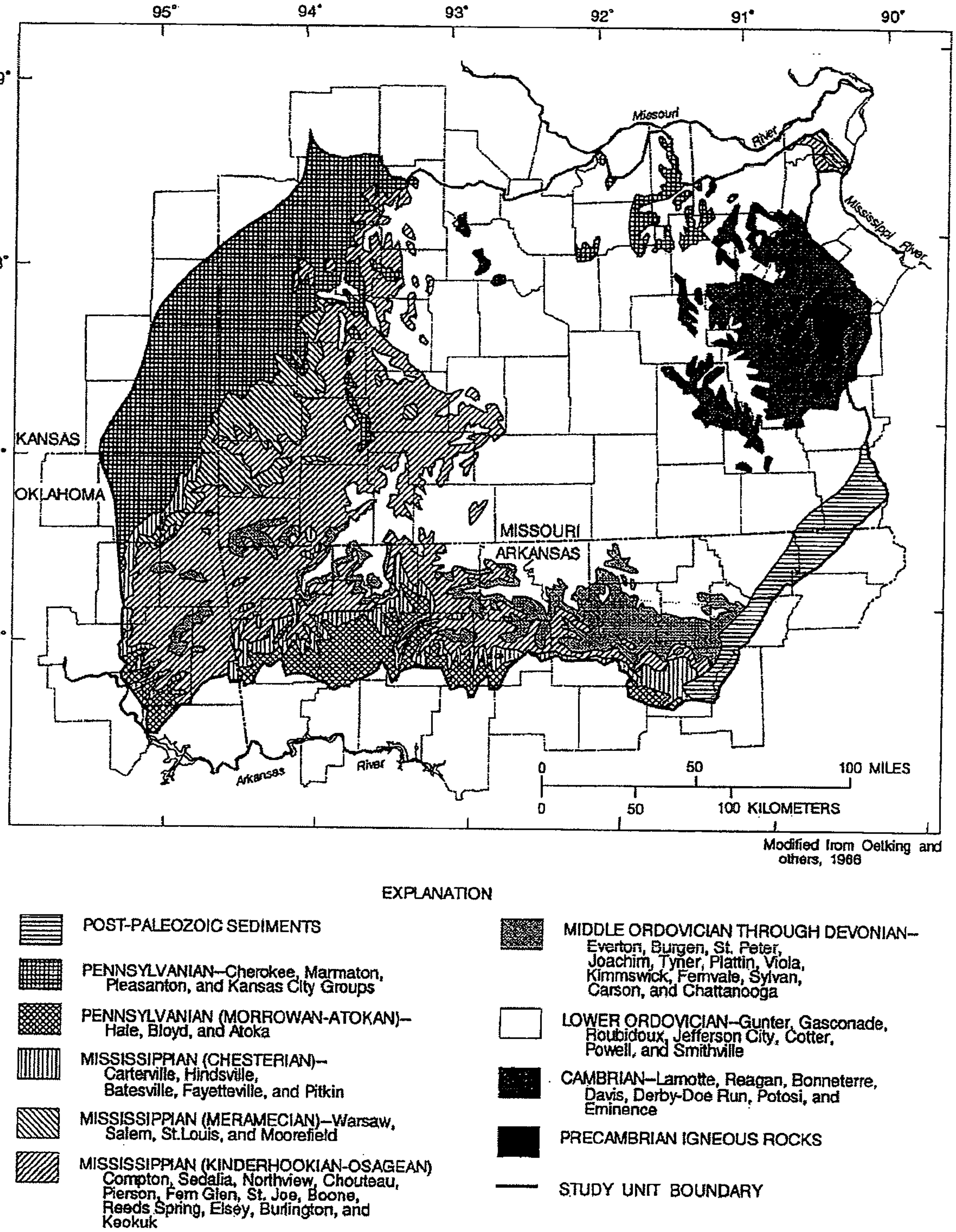


Figure 8. Geology of the Ozark Plateaus study unit.

and others, 1972). These dolomites are relatively impermeable compared to the other units of Cambrian and Ordovician age (Imes and Emmett, 1994).

The Potosi and Eminence Dolomites, which represent the top of the Cambrian section, are fine- to coarse-grained dolomites with dense chert, drusy quartz, and, in northern Arkansas, glauconitic green shale (Caplan, 1960). These units are exposed in southeastern Missouri. Thicknesses of the Potosi and Eminence Dolomites in Missouri average about 300 to 350 ft each (Howe and others, 1972), but total thickness for the two formations combined diminishes to 300 ft in northern Arkansas (Caplan, 1960). Both units contain barite, which has been mined in southeastern Missouri (Wharton and others, 1975).

The Gasconade Dolomite consists of a basal sandstone member, the Gunter Sandstone, and upper and lower dolomite members (MacDonald and others, 1975). It crops out extensively in southeastern Missouri. The Gunter Sandstone Member is a fine- to coarse-grained quartz sandstone, which can be dolomitic (Caplan, 1960). Thickness ranges from 30 to 120 ft. Chert is present in both dolomite members and can constitute more than 50 percent of the lower member. The upper dolomite member contains much less chert than does the lower member. Thickness of the Gasconade Dolomite ranges from 300 ft in central Missouri to more than 700 ft in northern Arkansas (MacDonald and others, 1975).

The Roubidoux Formation consists of sandstones, dolomites, and cherty dolomites (Thompson, 1991). It crops out extensively in central, south-central, and southeastern Missouri. The dolomites are fine to medium grained, and the sandstones are loosely cemented. In northern Arkansas, it can contain a few pyritic black shales. Thickness generally increases to the south-southeast and ranges from 100 to 450 ft (Caplan, 1960; Thompson, 1991).

The Jefferson City, Cotter, and Powell Dolomites, and the Smithville Formation consist of dolomite with chert, sandstone lenses, and a few shale beds. These units are pyritic, and the Smithville Formation contains lead and zinc ore. The units are exposed in southern Missouri and northern Arkansas (Caplan, 1960). Thickness of each unit averages about 200 ft (MacDonald and others, 1975).

The Everton Formation contains sandy dolomite and sandstone members, which crop out extensively in northern Arkansas. It contains a few shale beds, none of which are laterally continuous. It can exceed 1,000 ft in thickness (Frezon and Glick, 1959).

The St. Peter Sandstone unconformably overlies the Everton Formation and crops out mainly in northern Arkansas. It is a loosely cemented, well-rounded quartz sandstone that can be as much as 300 ft thick (McFarland and others, 1979). Its contact with the overlying Joachim Dolomite is lithologically gradational (Frezon and Glick, 1959).

Silurian and Devonian Units

Rocks of Silurian and Devonian age are thin, and most are not laterally continuous in the study unit. Most of the units in this interval exist only in northern Arkansas and parts of Missouri. The most significant unit is the black, pyritic, thinly bedded Chattanooga Shale. This shale ranges in thickness from less than 10 to 100 ft, but averages about 70 ft in thickness (Wise and Caplan, 1979). It contains phosphate, glauconite (Frezon and Glick, 1959), and minor amounts of uranium (Nuelle, 1987).

Mississippian Units

Rocks of Mississippian age in the study unit are predominantly fine- to coarse-grained limestones and cherty limestones. These units have a total thickness of about 200 to 500 ft (McFarland and others, 1979) and crop out extensively in the Springfield Plateau (fig. 8).

Because of lateral facies changes and independent geologic studies in different states, the same sequence of rocks has different nomenclature throughout the study unit. For example, the St. Joe Limestone and the Boone Formation in northern Arkansas are equivalent to the entire sequence from the Compton Limestone to the Keokuk Limestone in southern Missouri.

As with the underlying rocks of Cambrian and Ordovician age, secondary mineralization is extensive in the limestones of Mississippian age. Lead- and zinc-sulfide deposits are present in southwestern Missouri, southeastern Kansas, and northeastern Oklahoma. Pyrite, lead and zinc carbonates, and zinc silicates are also present in these deposits (Kiilsgaard and others, 1967).

Rocks of late Mississippian age overlie the Boone Formation and equivalent units and crop out on the northern flank of the Boston Mountains. These units include the relatively permeable Hindsville and Pitkin Limestones, which are separated by the thick, impermeable Fayetteville Shale. The Fayetteville Shale is a fissile, pyritic, and carbonaceous shale with abundant iron concretions. In north-central Arkansas, the shale is interbedded with thin layers of finely crystalline limestones (McFarland and others, 1979).

Pennsylvanian Units

Rocks of Pennsylvanian age crop out in the Boston Mountains of northern Arkansas, and in the Osage Plains of western Missouri, southeastern Kansas, and northeastern Oklahoma (fig. 8). In general, rocks of Pennsylvanian age rest unconformably on rocks of Mississippian age; however, in the north-central part of the study unit, rocks of Mississippian age are missing, and rocks of Pennsylvanian age directly overlie rocks of Ordovician age (fig. 8).

In northern Arkansas, three geologic units--the Hale Formation, the Bloyd Shale, and the Atoka Formation--are of Pennsylvanian age. The Hale Formation and Bloyd Shale are massive sandstones with limestone, shale, and coal beds. The Atoka Formation is mostly dark shales with sandstones and sandy limestones (Caplan, 1957). Total thickness of the section in the southern part of the study unit ranges from 1,000 to 2,000 ft (Imes, 1990g).

Rocks of Pennsylvanian age in western Missouri, southeastern Kansas, and northeastern Oklahoma consist of four groups--Cherokee, Marmaton, Pleasanton, and Kansas City--and have a combined thickness that ranges from 40 to 700 ft. Lithologies are mostly shales and sandstones with some limestones. Black shales in the section can be uranium-bearing (Coveney and others, 1987). Bituminous coal beds are present in the Cherokee and Marmaton Groups (Robertson and Smith, 1981). In places, these same units produce oil and gas (Anderson and Wells, 1967).

Post-Paleozoic Units

Sediments of Cretaceous through Quaternary age in the study unit consist of unconsolidated sands, gravels, and clays. These sediments crop out in the Mississippi Alluvial Plain and as thin alluvial deposits in some of the major stream valleys (fig. 8; Fenneman, 1938).

Structural Geology

The Ozark Plateaus Province is underlain by a structural dome formed by a series of uplifts that has occurred since Precambrian time. Total uplift is approximately 5,000 ft (McCracken, 1967).

The dome is asymmetrical; the dip of sedimentary rocks is greater to the east-southeast than it is to the south, west, or north (McCracken, 1967). For example, regional dip east of the St. Francois Mountains is 150 ft/mi (feet per mile; Tikrity, 1968), whereas regional dip in southwestern Missouri is about 10 ft/mi. The dip to the south increases to 200 ft/mi on the southern flank of the Boston Mountains as a result of faulting in the area (Frezon and Glick, 1959).

Extensive fracturing, jointing, and faulting of the rocks has resulted from the uplifting. Photo-lineament analyses of the Boone Formation in northwestern Arkansas indicate that fractures generally trend northwest, northeast, and east-west (Ogden, 1980; Adamski, 1987; Leidy and Morris, 1990). Joints are present in many of the rocks of Paleozoic age. Joints trend east-west, north-south, northwest-southeast, and northeast-southwest. Dip of these joints generally is vertical (McCracken, 1971).

Major faults in the Ozark Plateaus trend northwest (McCracken, 1967). Displacement can be as much as 1,000 ft. Some of the major faults form escarpments visible for several miles (Beveridge and Vineyard, 1990).

Several distinct ring-shaped fault systems exist in the Ozark Plateaus of Missouri. One such structure, the Decaturville Structure in Camden County, Missouri, is about 4 mi in diameter. It consists of a pegmatite of Precambrian age exposed in the center and surrounded by rocks of Ordovician age (Offield and Pohn, 1979).

Geological History

Granite and rhyolite rocks of Precambrian age crystallized about 1.2 to 1.5 billion years ago in the Ozark Plateaus and adjacent areas (Tikrity, 1968). These igneous rocks form the basement complex of the study unit. After igneous activity ceased, the landscape was eroded prior to Late Cambrian time when the Lamotte Sandstone and Bonneterre Dolomite were deposited (McCracken, 1971). Deposition of marine carbonates was nearly continuous, with brief periods of erosion and deposition of clastic sediments, from Late Cambrian to Middle Ordovician time (Frezon and Glick, 1959). The area was extensively eroded prior to the deposition of the Everton Formation (C.E. Robertson, Missouri Division of Geology and Land Survey, written commun., 1992).

After deposition of the Everton Formation, the Ozark Plateaus area was uplifted and the sediments were extensively eroded. Geologic units from the St. Peter Sandstone through Fernvale Limestone were subsequently deposited, but uplifting limited sediment deposition from Middle Ordovician to Early Devonian time. After the Early Devonian time, the Ozark Plateaus area was uplifted again and eroded (McCracken, 1971).

Sediments of Middle Devonian and Mississippian age were subsequently deposited in the study unit. Limestones of Mississippian age were deposited in shallow seas that inundated the Ozark Plateaus area. After Mississippian time, the northern part of the Ozark Plateaus area was uplifted and tilted. Rocks of Devonian and Mississippian age were beveled, exposing rocks of Ordovician age over much of the area (Frezon and Glick, 1959; McCracken, 1971).

Sediments of Pennsylvanian age were deposited by transgressing seas and by riverine systems, in places, directly on the exposed rocks of Ordovician age. Periodic uplifts formed unconformities in the rocks of Pennsylvanian age. The Ozark Plateaus area was uplifted and extensively eroded after Pennsylvanian time (McCracken, 1971).

The fluvial and marine sediments were deposited in Late Cretaceous and early Tertiary time. Subsequent uplifting exposed the area to erosion, generating the current topography (McCracken, 1971).

Soils

Three types of soils--mollisols, alfisols, and ultisols--underlie most of the study unit (fig. 9). Mollisols, which are the dominant soil in the Osage Plains, form under prairies on sandstones, limestones, and shales (Persinger, 1977). These soils are agriculturally productive, having thick, dark upper horizons that are dominated by divalent cations. This horizon has a crumbly or granular texture (Brady, 1984).

Alfisols and ultisols are the dominant soil types underlying the Ozark Plateaus and the Mississippi Alluvial Plain (Allgood and Persinger, 1979). These soil types, which generally form under deciduous forests in warm, humid climates, are moderately to strongly weathered. These soils commonly contain an abundance of kaolinite, illite, and iron and aluminum oxides, are depleted in organic matter, and can be acidic (Brady, 1984).

Soil series in the study unit are extremely diverse; therefore, it is difficult to generalize hydrologic characteristics. In Boone County, Arkansas, for example, parts of which lie in the Boston Mountains, Springfield Plateau, and Salem Plateau, 19 soil series have been identified. Soil thickness for these series ranges from 0 to 84 in., permeability ranges from 0.06 to 6.00 in/hr (inches per hour), and pH ranges from 3.6 to 8.4 (Harper and others, 1981). In Benton, Fulton, Izard, and Newton Counties, Arkansas, organic matter constitutes from 0.2 to 6 percent of the soil (Phillips and Harper, 1977; Ward and Rowlett, 1984; Fowlkes and others, 1988).

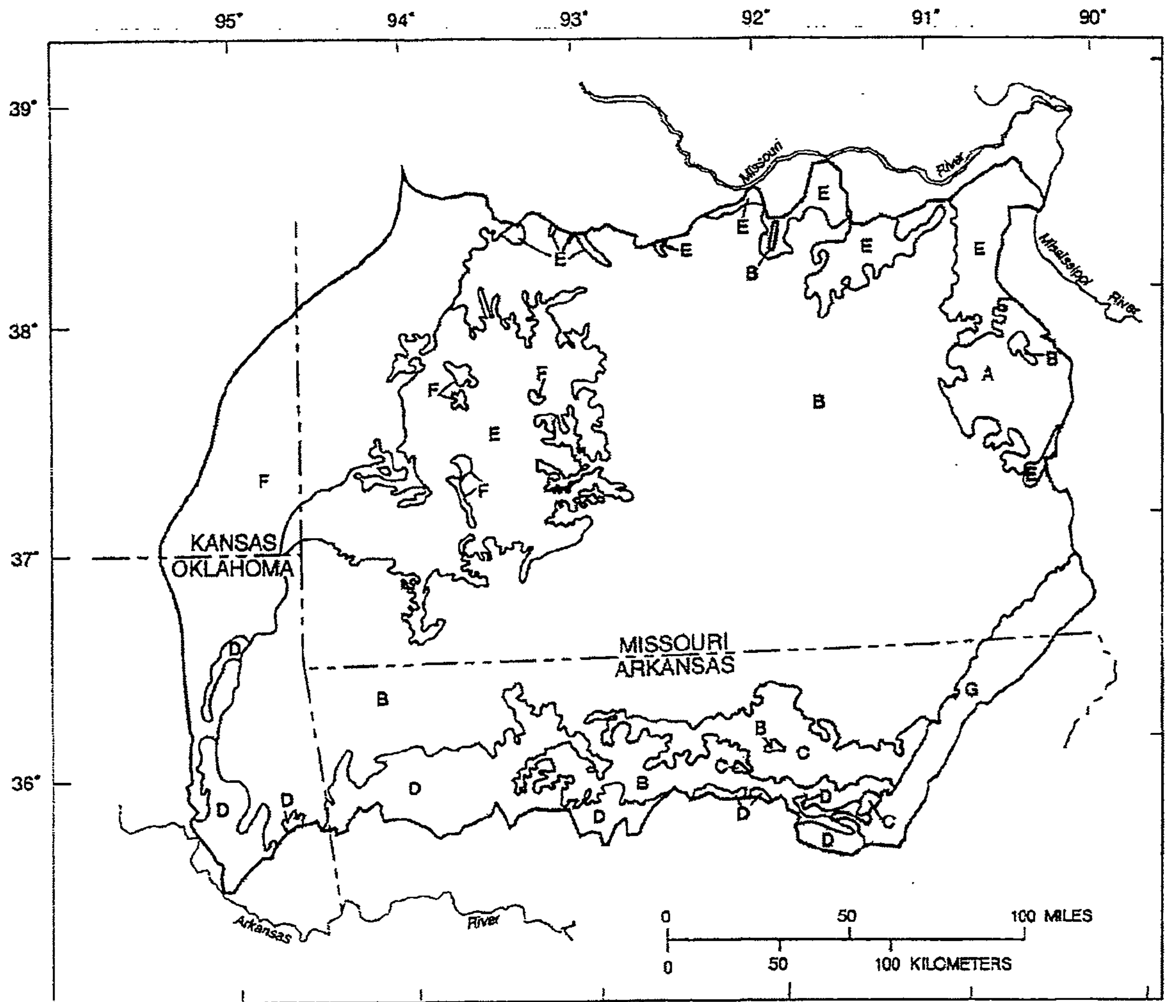
In general, most of the soils in the study unit have a high potential for nutrients and other dissolved constituents to be leached to the ground water and have a high potential for runoff to surface water systems. Leaching potential is high for 65 percent of the soils in Boone County, Arkansas; runoff potential is severe for 38 percent of the soils (Rick Fielder, U.S. Soil Conservation Service, written commun., 1992). In addition, erosion potential is moderate to high for soils in the Ozark Plateaus. Erosion factors range from 0.10 to 0.49 in Boone, Fulton, Izard, and Newton Counties, Arkansas (Harper and others, 1981; Ward and Rowlett, 1984; Fowlkes and others, 1988). Erosion factors greater than 0.40 are considered high (Rick Fielder, oral commun., 1992).

In places, several diverse soil series are closely associated and, therefore, difficult to map separately. Arkana and Moko soil series account for nearly 22 percent of the soils in Boone County, Arkansas. Arkana soils have a low leaching potential and a moderate runoff potential. Moko soils have a high leaching potential and a severe runoff potential. In 91 percent of the total area of distribution, Arkana and Moko soils are closely associated, forming a combined soil with diverse hydrologic characteristics (Harper and others, 1981).

Population

The 1990 population within the Ozark Plateaus study unit was approximately 2.3 million people. In the study unit, the population distribution was about 1.6 million in Missouri, 420,000 in Arkansas, 150,000 in Oklahoma, and 81,000 in Kansas (fig. 10; U.S. Department of Commerce, Bureau of Census, 1990).

Population in the study unit increased about 28 percent between 1970 and 1990. Counties having pop-



Modified from Persinger, 1977; U.S. Soil Conservation Service, 1982; Gray, 1959; U.S. Soil Conservation Service, 1986

EXPLANATION

SOIL TYPES

- A — OZARK DOME–Alfisols and Ultisols
- B — OZARK HIGHLANDS (DOLOMITES)–Alfisol and Ultisols
- C — OZARK HIGHLANDS (SANDSTONES AND LIMESTONES)–Ultisols, Alfisols, and Mollisols
- D — BOSTON MOUNTAINS–Ultisols and Alfisols
- E — OZARK BORDER–Ultisols and Alfisols
- F — OZARK PLAINS–Mollisols and Alfisols
- G — MISSISSIPPI ALLUVIAL PLAIN–Alfisols and Ultisols

—— STUDY UNIT BOUNDARY

Figure 9. Major soil types of the Ozark Plateaus study unit.

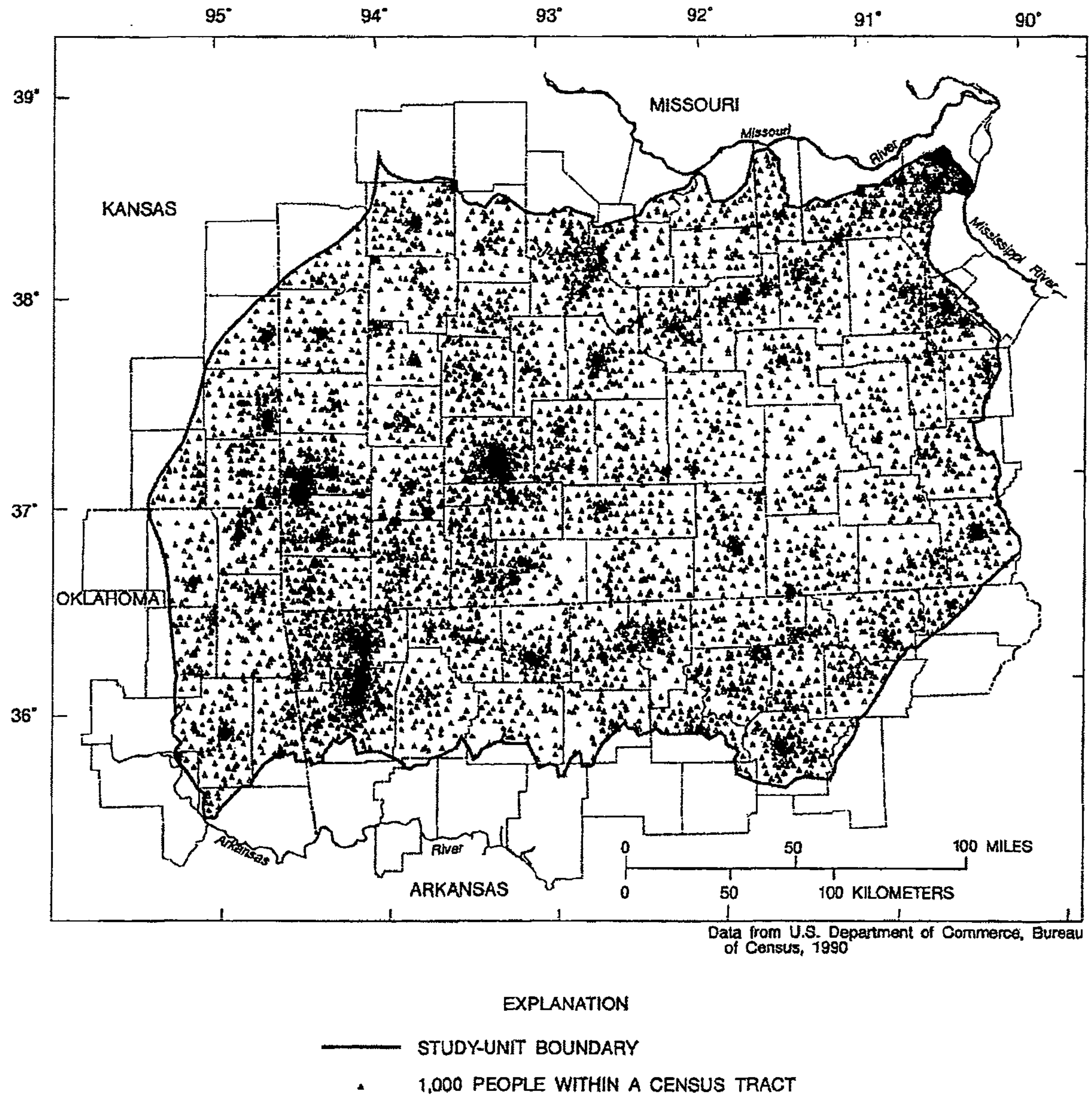


Figure 10. Population distribution in the Ozark Plateaus study unit, 1990.

ulation increases of 25, 50, 75, and 90 percent since 1970 are shown in figure 11. The largest percentage increases in population within the study unit were in southern Missouri and northern Arkansas. The population of some counties in northern Arkansas has increased more than 50 percent, and the population of several counties in southern Missouri has increased 90 percent in the last two decades.

Recreational activities attract many tourists to southern Missouri and northern Arkansas during the spring, summer, and fall. For example, Branson, Missouri (fig. 11), which has a resident population of only 3,700 people, was visited by an estimated 4.2 million tourists in 1991 (U.S. Department of Commerce, Bureau of Census, 1990).

Large urban areas are not common in the study unit. Springfield, Missouri, is the only city in the study unit with a population exceeding 100,000 people. The only urban areas in the study unit having populations exceeding 20,000 residents are Joplin, Missouri, and Fayetteville, Rogers, and Springdale, Arkansas (fig. 11; table 2; U.S. Department of Commerce, Bureau of Census, 1990).

Table 2. Population of the largest cities within the Ozark Plateaus study unit

[Source: U.S. Department of Commerce, Bureau of Census, 1990]

City	Population, 1990
Springfield, Missouri	140,494
Fayetteville, Arkansas	42,099
Joplin, Missouri	40,961
Springdale, Arkansas	29,941
Rogers, Arkansas	24,692

Land Use

Land use in the Ozark Plateaus and adjacent areas prior to European settlements was primarily oak-hickory forests on the hilly regions and bluestem prairie on the undissected plateaus. The upland forests generally consisted of old-growth oak-hickory or oak-hickory-shortleaf pine stands. Lowland forests had a greater variety of species than upland forests and included sycamores, cottonwoods, maple, black walnut, butternut, hackberry, poplar, and bur oaks. Prairies were common only in small patches in the eastern part of the Ozark Plateaus but about 50 percent of the western part was in prairie grasslands. The prairie vegetation was primarily composed of bluestem grasses. Trees were not well established in these prairies because Native Americans periodically burned the vegetation to drive game. Early settlers continued the practice of burning to provide pastureland; after the Civil War, however, many of the prairies were allowed to revert to forests (Rafferty, 1980).

A majority of the woodlands of the Ozarks Plateaus study unit are now second or third growth due to intense logging through the years. However, tree species in the woodlands are similar to those of the old-growth forests.

Currently (1993) land use in the Ozark Plateaus study unit consists primarily of forest, pasture, and some cropland (fig. 12). Deciduous forestland, mostly oak and hickory trees, predominate in the Salem Plateau and Boston Mountains, which often is mixed with pine trees in the White River Basin. Pastureland, which is mostly fescue (used as hay) and Kentucky blue grass, is grown in the river bottoms and gentle to steep slopes of the uplands in the Springfield Plateau. Cropland is the predominant land use in the Osage Plains and Mississippi Alluvial Plain. Soybeans and sorghum with some corn, wheat, grains, and other field crops are grown in the Osage Plains, with rice dominating in the Mississippi Alluvial Plain.

Poultry, beef and dairy cattle, and swine are the dominant livestock raised in the pasturelands of the Ozark Plateaus study unit. Large concentrations of poultry farms are in the southwestern part of the study unit and in a small area around Miller County, Missouri. Intensive poultry farming started mainly around northwestern Arkansas in the 1930's and has expanded greatly into southwestern Missouri and northeastern Oklahoma in recent years (Rafferty, 1980). Dairy cattle farming is a major land use in the central part of the study unit. Commercial dairy farming grew rapidly from the early through the mid-1900's in southwestern Missouri and northwestern Arkansas. In recent years, dairy farming in the study unit has declined slightly. Beef cattle and hogs are raised throughout most of the study unit (Rafferty,1980).

Throughout much of the early and mid-1900's, mining was a major land use in parts of the Ozark Plateaus study unit. The study unit contains major deposits of lead, zinc, iron, barite, coal, and minor deposits of copper, silver, manganese, and tungsten and has a long

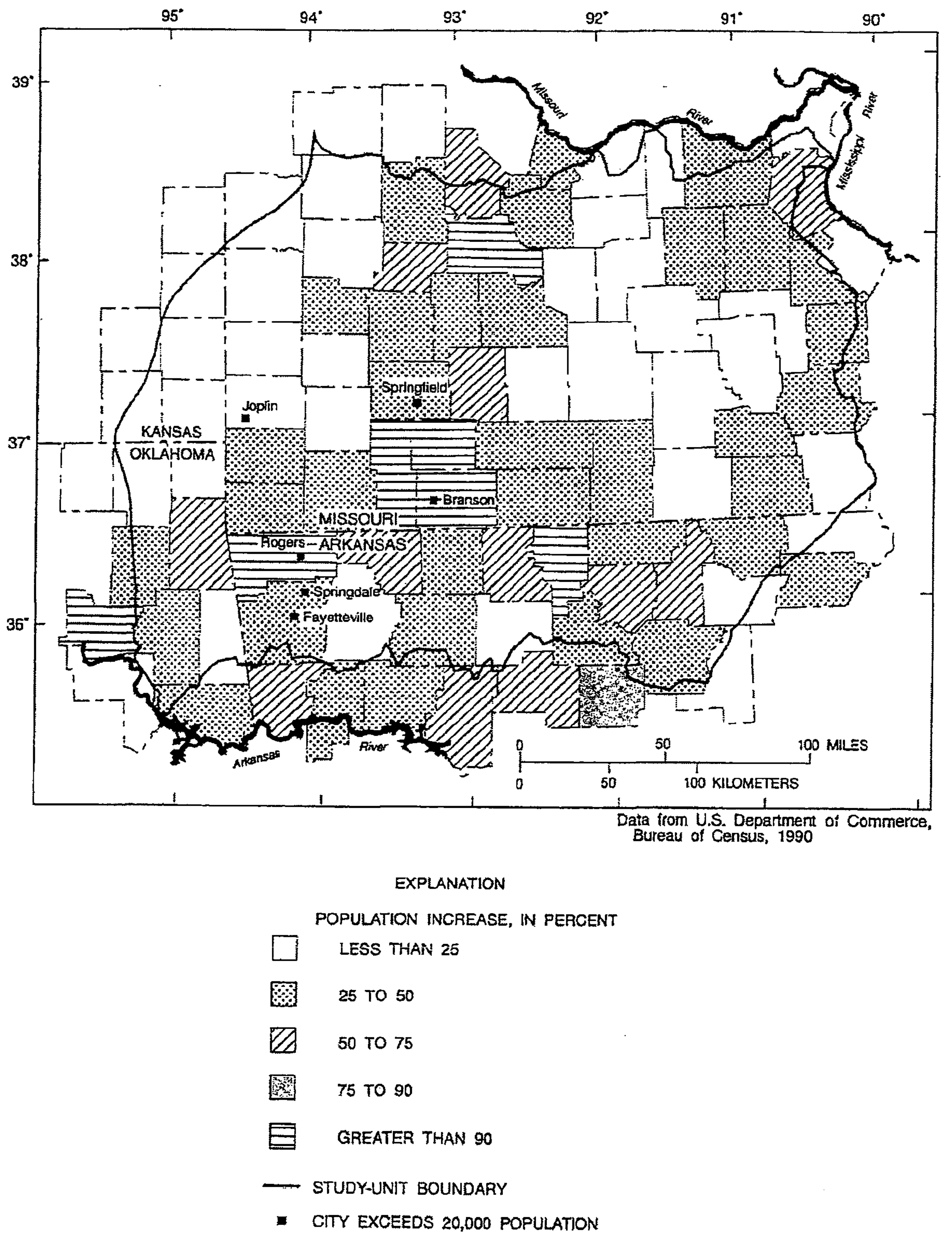


Figure 11. Percentage increase in population by county, 1970-90, and location of cities with 1990 population exceeding 20,000.

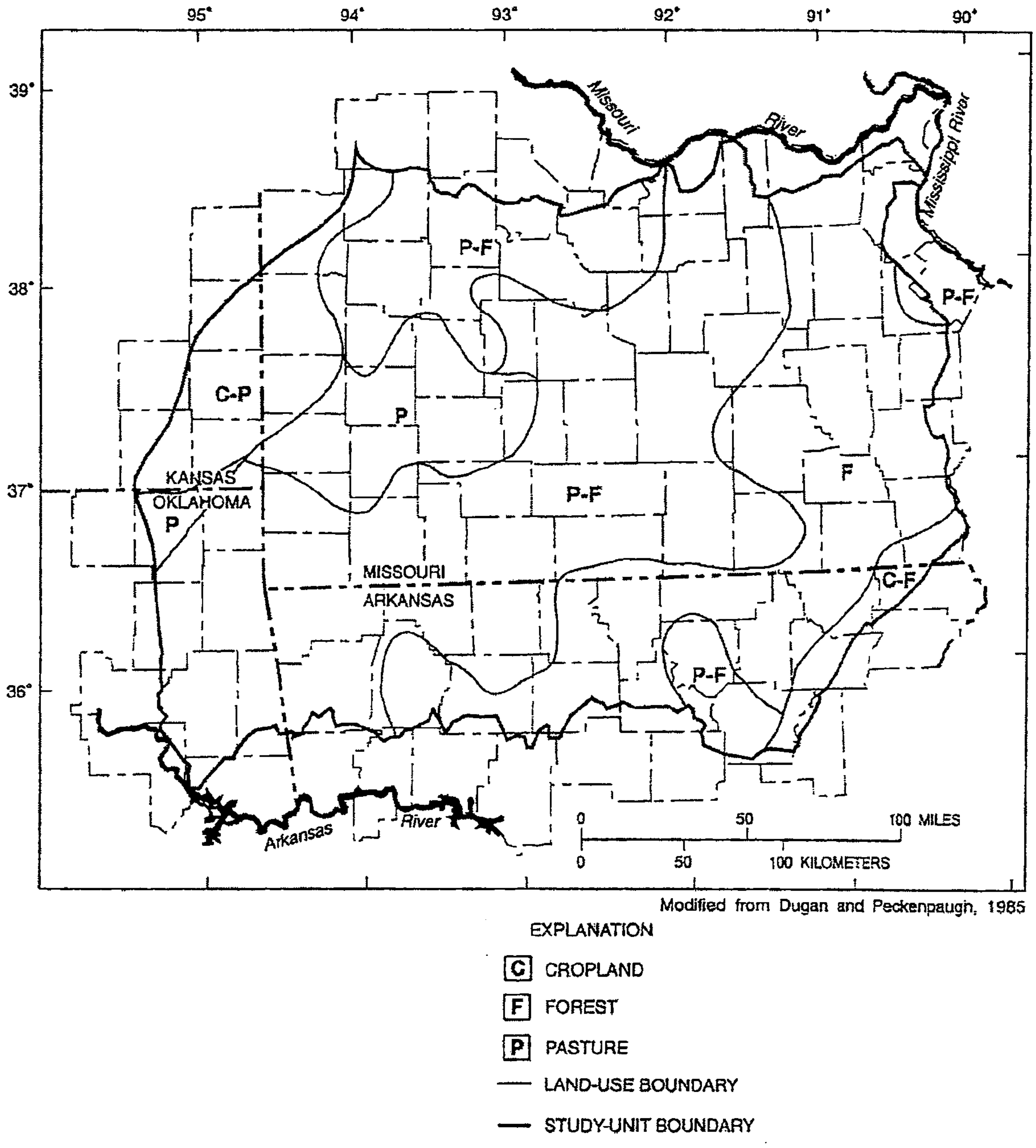


Figure 12. Generalized land use in the Ozark Plateaus study unit.

history as a major producer of lead and zinc. Mining activities in the study unit have occurred primarily in four main lead-zinc mining districts--the Southeastern District (Old Lead Belt, Viburnum Trend, and the Fredericktown subdistricts), the Tri-State District, the Central District, and the North Arkansas District (fig. 13). By far, the most important ore deposits were in the Tri-State District and the Southeastern District (Wharton and others, 1975). The Southeastern District was primarily a lead producer, and the Tri-State District was primarily a lead and zinc producer (Wharton and others, 1975). The Central and the North Arkansas Districts contained relatively small, scattered ore deposits that were not mined as actively as were deposits in the two major lead-zinc mining districts (Rafferty, 1980). The Viburnum Trend subdistrict is the only area still actively mined for lead and zinc (Wharton and others, 1975).

Bituminous coal deposits underlie the northwestern part of the study unit. The coal is present in numerous beds, all associated with rocks of Pennsylvanian age (Robertson and Smith, 1981). Historically, coal production in this area has fluctuated with national and international economic conditions. Until 1925, most of the coal was mined underground. Approximately two-thirds of the coal mined is used to produce electricity (Searight, 1967).

Water Use

Freshwater withdrawals or use from both surface- and ground-water sources within the Ozark Plateaus study unit averaged about 1,053 Mgal/d in 1990. A summary of water use for parts of Arkansas, Kansas, Missouri, and Oklahoma that are within the study unit is presented in table 3. Nonconsumptive withdrawals, such as water withdrawn by power generating plants, are not included in the data given in this table. Water use by county in the Ozark Plateaus study unit is shown in figure 14. Withdrawals within the study unit for counties only partly within the study unit were estimated from county totals and the percentage of the county within the study unit. Of the total water used in the study unit in 1990, approximately 58 percent was withdrawn from ground-water sources and 42 percent from surface-water sources. Ground-water use for irrigation accounted for 39 percent of the total, primarily for rice production from counties in the Mississippi Alluvial Plain. Surface-water use for public supply, primarily from reservoir systems in northwestern Arkansas, southwestern Missouri, and northeastern Oklahoma, accounted for 20 percent of the total water used in the study unit. Withdrawals for agriculture, commercial, domestic, industrial, and mining use categories were each less than 100 Mgal/d in 1990.

SURFACE WATER

Surface-water resources are abundant in the Ozark Plateaus study unit. Several major rivers and large reservoirs are located within the study unit. Most rivers flow radially away from the central part of the Springfield-Salem Plateaus or the Boston Mountains.

Major Rivers, Tributaries, and Reservoirs

The Ozark Plateaus study unit is drained by seven major river basins--the White, Neosho-Illinois, Osage, Gasconade, Meramec, Black, and St. Francis Rivers

Table 3. Water use within the Ozark Plateaus study unit, 1990

[SW, surface water; GW, ground water; units are million gallons per day. Source: Aggregated Water Use Data System (AWUDS) data base maintained by U.S. Geological Survey office in each state]

	Agriculture		Commercial		Domestic		Industrial		Irrigation		Mining		Public supply		Total		Total water use
State	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	
Arkansas	18	7	85	0	0	11	19	0	27	272	0	0	51	12	200	302	502
Kansas	2	1	0	0	0	0	4	0	1	0	0	0	4	6	11	7	18
Missouri	17	6	0	10	0	32	21	18	24	140	0	25	96	65	158	296	454
Oklahoma	9	1	0	0	0	4	0	0	4	0	0	0	57	4	70	9	79
	46	15	85	10	0	47	44	18	56	412	0	25	208	87	439	614	1,053

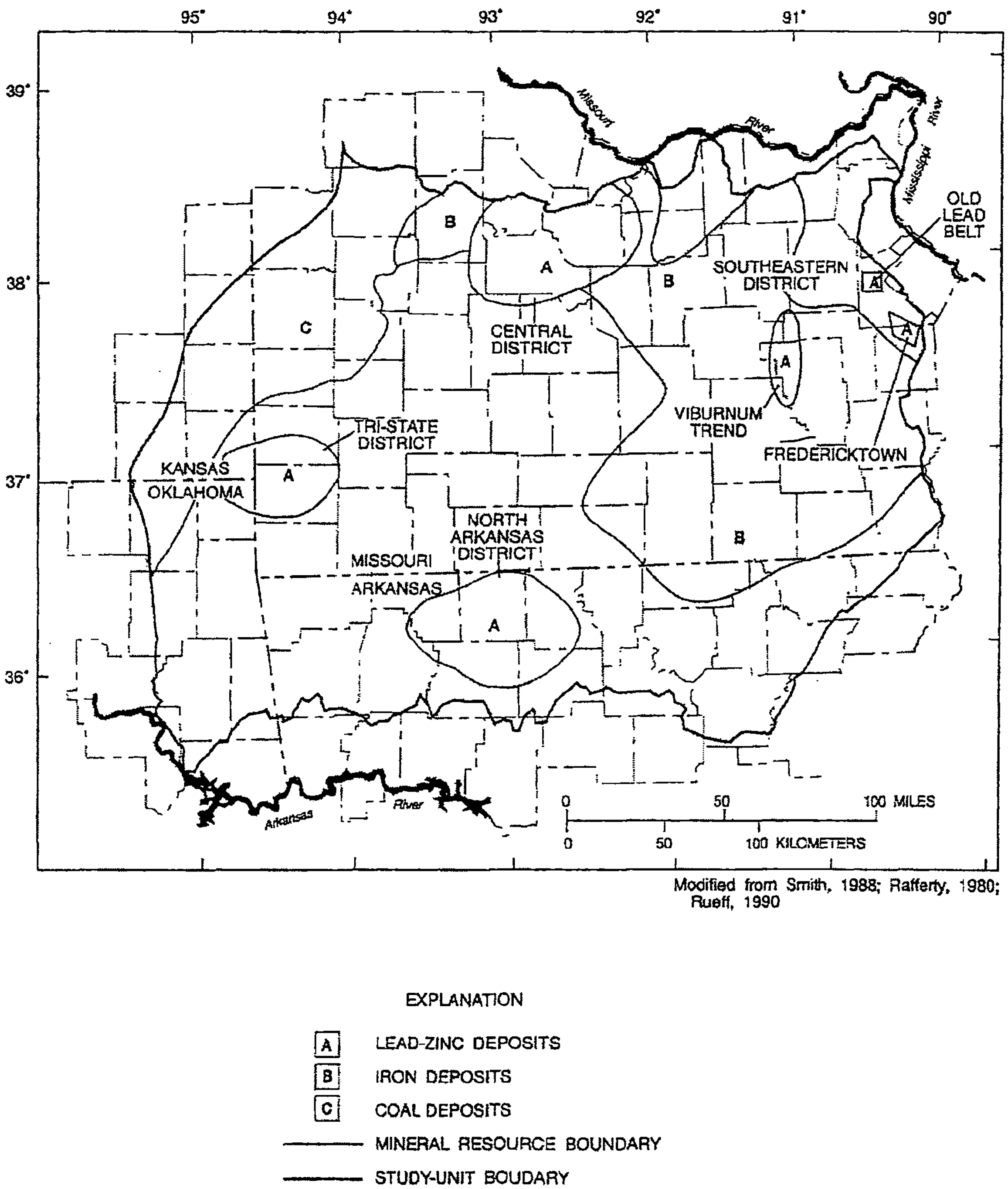


Figure 13. Mineral resources in the Ozark Plateaus study unit.

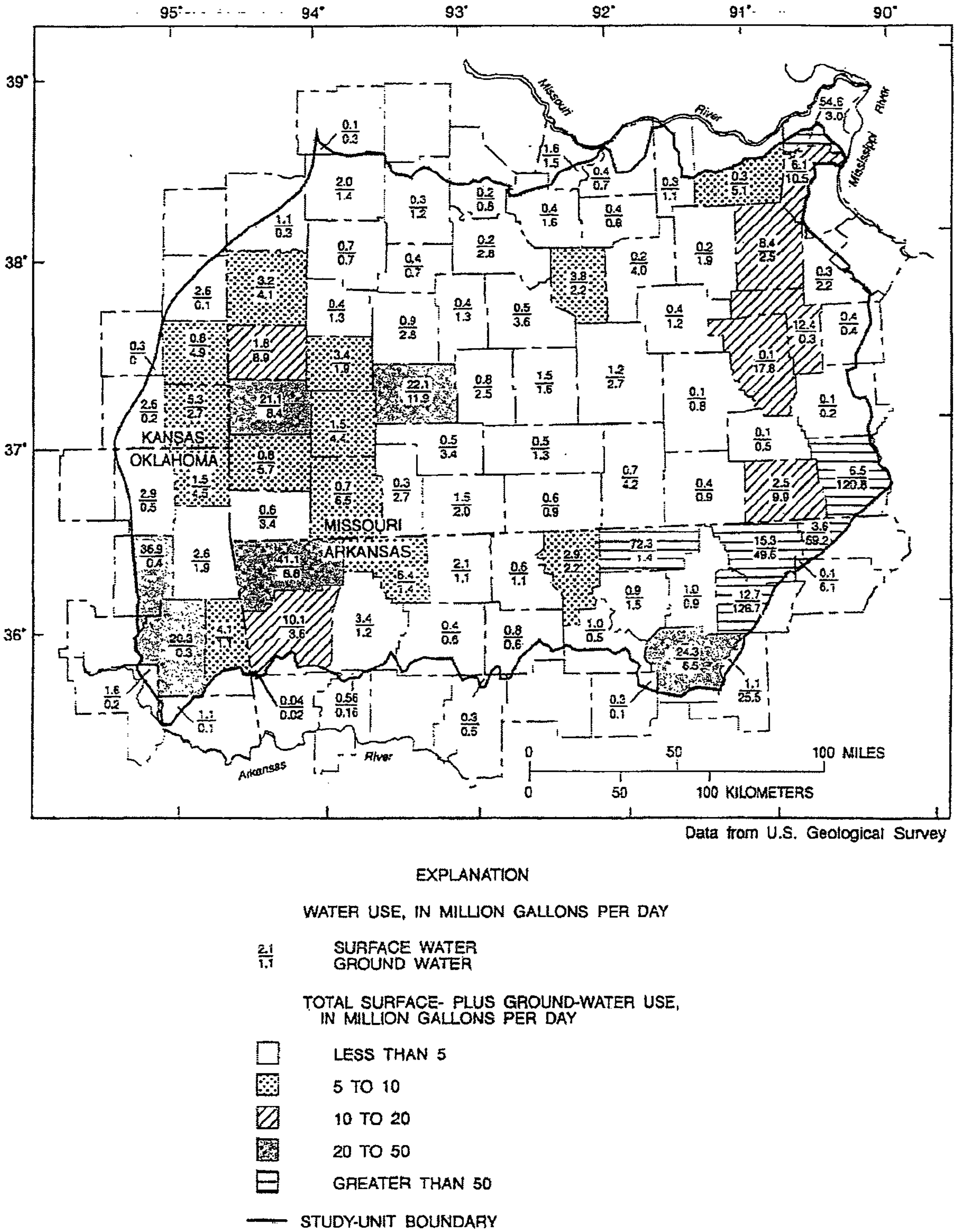


Figure 14. Water use by county in the Ozark Plateaus study unit, 1990.

(fig. 15; table 4)--that either directly or indirectly flow into the Mississippi River. The Black River is a tributary of the White River, which flows directly into the Mississippi River, as do the Meramec and St. Francis Rivers. The Neosho and Illinois Rivers are tributaries to the Arkansas River, which flows into the Mississippi River. The Osage and Gasconade Rivers flow into the Missouri River, which is the largest of the Mississippi River tributaries.

White River

The White River originates in the rugged terrain of the Boston Mountains of northwestern Arkansas, generally flows northward to the Arkansas-Missouri State line, then eastward through southern Missouri for about 115 mi where it intersects the State line again (fig. 15). The river meanders along the Arkansas-Missouri boundary for about 30 mi, flows southeastward into Arkansas to the mouth of the Black River (fig. 16), and then south to its confluence with the Mississippi River. The total drainage area of the White River is 27,800 mi^2, with about 10,600 mi^2 in southern Missouri and 17,200 mi^2 in northern and eastern Arkansas. About 11,300 mi^2 (not including the Black River Basin) are in the Ozark Plateaus study unit (Sullavan, 1974). The reach of the White River near the Arkansas-Missouri State line is a series of reservoirs, beginning with Beaver Reservoir in northwestern Arkansas and then proceeding downstream to Table Rock Lake, Lake Taneycomo, and Bull Shoals Lake. Norfork Lake is on a tributary to the White River downstream from Bull Shoals Lake. With the completion of Powersite Dam on the White River in 1912, Lake Taneycomo was the first major impoundment of water for power production in Missouri (U.S. Army Corps of Engineers, 1967). The areas near these lakes in both Arkansas and Missouri are increasingly popular recreational attractions and retirement areas.

Major tributaries to the White River in Arkansas are War Eagle Creek, Kings River, Crooked Creek, and Buffalo River. In 1972, the Buffalo River was designated the Buffalo National River by Congress (Public Law 92-237) "for the purposes of conserving and interpreting an area containing unique scenic and scientific features, and preserving as a free-flowing stream an important segment of the Buffalo River..." (Mott, 1991). Headwaters of War Eagle Creek, Kings River, and Buffalo River are in the Boston Mountains, but most of these basins lie within the Springfield Plateau (War Eagle Creek) or the Springfield and Salem Plateaus (Kings River and Buffalo River). Crooked Creek lies mainly in the Salem Plateau, but its headwaters are in the Springfield Plateau. Land use in this part of the White River Basin is primarily forest with pasture and some cropland.

The James and North Fork White Rivers are major tributaries to the White River in Missouri. Most of the James River Basin lies within the Springfield Plateau with the exception of the lower part of the basin where the James River or tributaries have incised rocks of Ordovician age in the Salem Plateau. The lower part of the basin is primarily forested, whereas the upper part is predominately pasture and cropland agriculture. Springfield, Missouri, the largest urban area in the study unit, lies within the James River Basin. The North Fork White River Basin lies entirely in the Salem Plateau and is about 70 percent forested. The lower part of the river has been impounded to form Norfork Lake.

Neosho-Illinois Rivers

The Neosho River originates in east-central Kansas in the gently rolling hills of the Osage Plains (fig. 15). Land in this part of the basin is used principally for cropland and pasture, although coal and lead-zinc mining has occurred in the basin. The river flows toward the southeast through Kansas into Oklahoma. Below the confluence with the Spring River, a major tributary, the river then follows a winding course through a chain of reservoirs before entering the Arkansas River (fig. 17). These reservoirs are popular recreational attractions. The lower part of the basin, which is predominantly in Missouri and Oklahoma, lies in the Springfield Plateau. The total drainage area of the Neosho River Basin is about 12,500 mi^2, but only about 60 percent of the drainage area (7,600 mi^2) is in the study unit. The largest urban area in the basin within the study unit is Joplin, Missouri. A major tributary to the Neosho River, the Elk River, lies entirely in the Springfield Plateau and drains pasture and forest in northern Arkansas and southwestern Missouri.

The Illinois River originates in northwestern Arkansas, flows generally to the north and then to the southwest into Oklahoma where it flows into the Arkansas River (fig. 17). The lower part of the river is impounded to form Tenkiller Ferry Lake. The basin (about 1,630 mi^2) lies entirely within the study unit and is mostly in the Springfield Plateau. The headwaters of the basin are in the Boston Mountains. From the Arkan-